



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>

Preparatory Physics

HOPKINS



HARVARD UNIVERSITY

LIBRARY OF THE

Department of Education

COLLECTION OF TEXT-BOOKS

Contributed by the Publishers

HARVARD COLLEGE
LIBRARY



3 2044 097 016 604

PREPARATORY PHYSICS.

PREPARATORY PHYSICS

A Short Course in the Laboratory

BY

WILLIAM J. HOPKINS

PROFESSOR OF PHYSICS IN THE DREXEL INSTITUTE OF ART, SCIENCE, AND
INDUSTRY, PHILADELPHIA

AUTHOR OF "TELEPHONE LINES AND THEIR PROPERTIES"

NEW YORK

LONGMANS, GREEN, AND CO.

1894

Educ 7 1894. 455

Harvard College Library

Dec 20, 1918.

Transferred from

Education Library.

COPYRIGHT, 1894, BY

LONGMANS, GREEN, AND CO.

TROW DIRECTORY
PRINTING AND BOOKBINDING COMPANY
NEW YORK

PREFACE.

AN exposition of the advantages of laboratory work in science in training the hand and the eye and in developing the student's powers of perception and logical reasoning is, at the present day, unnecessary. The benefit of such work, as preliminary to the undertaking of any thorough or advanced work in science, particularly in physical science, is generally acknowledged.

The course here presented is the outgrowth of the needs of the classes beginning the study of physics in the Drexel Institute. It is intended primarily as a preparation for the more advanced work in general physics ; to develop habits of accurate and thorough observation, careful and complete record and orderly arrangement, and to give that training in the handling of apparatus that is so necessary for the beginner. To accomplish these purposes it has seemed to me best not to attempt to cover the whole ground of physics. What is done should be done thoroughly. The subject of Mechanics has, therefore, been selected for the fullest treatment, as being fundamental, particularly susceptible of treatment in this manner, with comparatively simple apparatus ; and because the student is very greatly aided in thoroughly comprehending its problems by investigating them experimentally. The work is quantitative throughout. Qualitative work in the physical laboratory is of little or no value as training for the beginner. The instructions are very explicit, for it has been my experience that immature students are very prone to be lax and shiftless both in observing and in recording, and that they will

carefully omit doing what they are not specifically instructed to perform. The general text before each experiment is sufficiently full to enable the experimental work to be well understood, and to prevent the students going off on a wrong track.

It may be well to state here my reasons for omitting a portion of the experiments recommended in the "Harvard pamphlet." It is obviously desirable that all experiments performed by the student, especially if he is a beginner, shall give results sufficiently near the truth to inspire him with confidence in his own work and in experimental methods of investigation. This condition is admirably fulfilled by the work on Mechanics, for with proper care, even with the somewhat rough apparatus employed in this course, it is possible to obtain results which differ not more than one per cent. from the true values.

In some other branches of the subject, I have not found this to be the case. In investigating the subject of latent heat, for example, or that of specific heat, it is necessary, in order to obtain accurate results, to employ more elaborate apparatus and much more careful and exact methods of research than are possible in such a course as is here presented. A student of this grade, using crude apparatus, will obtain results which may differ as much as fifty per cent. from the truth. This can do nothing but harm. It will lead him to distrust laboratory methods as means of ascertaining the truth, and to suppose that, as he himself cannot expect to obtain accurate quantitative results, it is not necessary for him to exercise care either in his reasoning or in his work.

For these reasons, based upon my own experience with students beginning the serious study of science, I have omitted all work upon specific heat, latent heat, velocity of sound and measurement of wave length of sound. I have omitted all work upon electric currents and electro-magnetism for two reasons: First, because there is scarcely

a boy now in our schools who has not considerable practical elementary knowledge of these subjects ; and, second, because I have found that such experiments serve more for the entertainment and amusement of the student than for his instruction. I believe that the study of these subjects is best left until a more advanced stage, when it can be taken up systematically and thoroughly.

The subject of Light, also, is one which, for similar reasons, I prefer to leave untouched in this course ; but as some of the experiments in this subject admit of accuracy with very simple apparatus, I have added a few. I believe, however, that this course will be found sufficiently complete without them, to constitute a thorough preparation for the college course.

The course occupies very comfortably about twenty-five two-hour periods, and has been given with good success without recitations or class-room work of any kind. It has been found advantageous to allow each student to go ahead with his work as rapidly as his individual capacity and attainments permit, and not to attempt class-work in the laboratory. This imposes a somewhat more severe duty on the instructor, but results in better work and a better spirit of work on the part of the student. A section of twelve is as large as one instructor can properly take care of in a two-hour period, and still better work will be done if two instructors are available for a section of fifteen to twenty students.

Full instructions are given for the apparatus needed. Care has been taken to make it simple, and to make as few pieces as possible serve. I am indebted to Mr. J. E. Ives, my assistant, for valuable suggestions, and to the writings of Professor S. W. Holman, of the Massachusetts Institute of Technology, in preparing the introductory matter on physical measurement.

W. J. H.

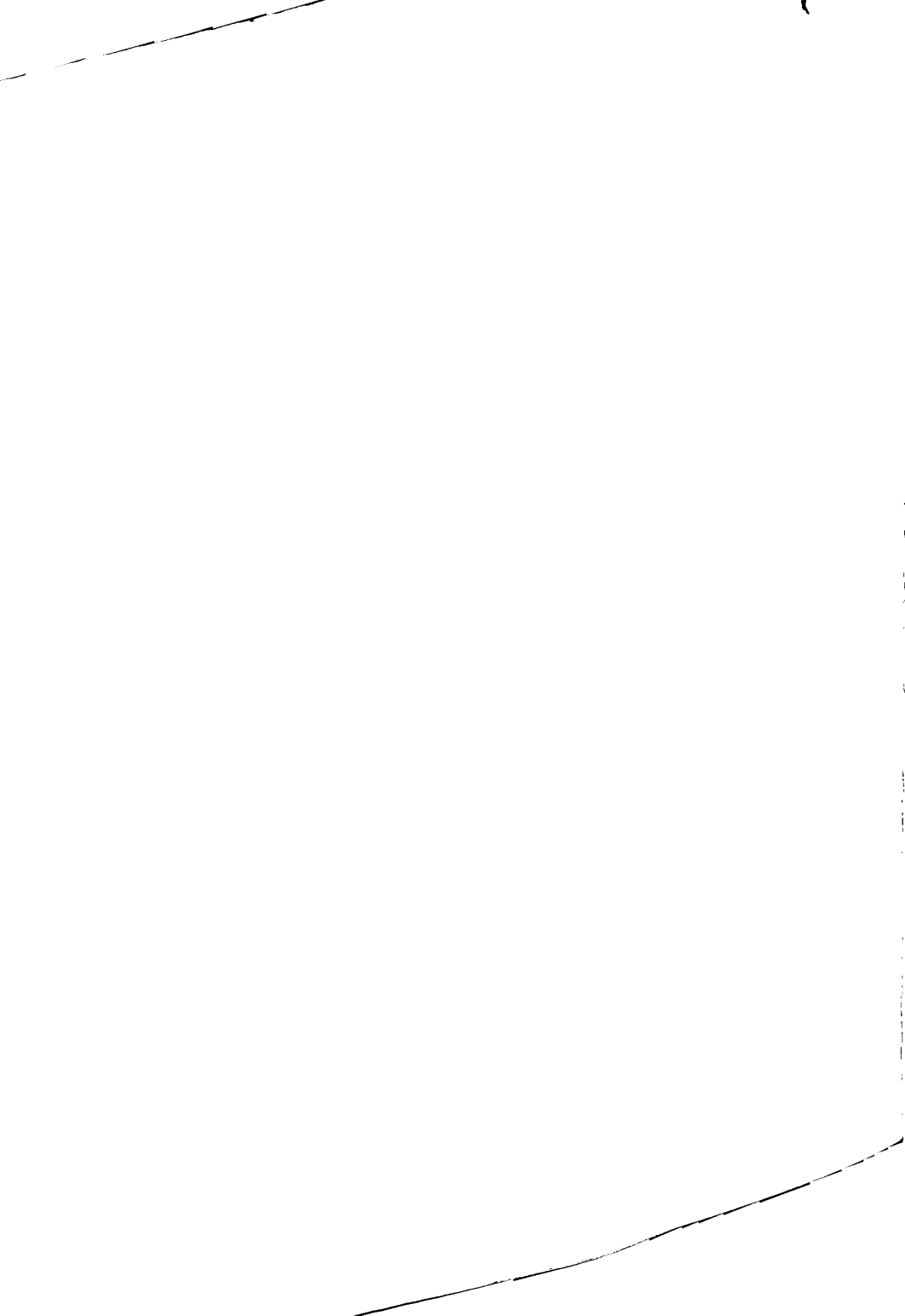


TABLE OF CONTENTS.

	PAGE
PHYSICAL MEASUREMENT, ...	1
Units and Standards, ...	1
Direct Measurement, ...	2
Error, ...	2
Sources of Error, ...	2
Deviation, ...	3
Determinate and Indeterminate Errors, ...	4
Mistakes, ...	4
Distribution of Deviations, ...	4
Significant Figures, ...	5
DISCUSSION OF OBSERVATIONS UPON RELATED QUANTITIES, ...	6
Plotting Curves, ...	7
INSTRUCTIONS FOR NOTE-BOOKS, ...	10
MENSURATION—LENGTH, ...	12
MENSURATION—VOLUME, ...	17
MENSURATION—WEIGHT, ...	23
COMPOSITION OF FORCES.	26
PARALLEL FORCES, ...	31
CENTRE OF GRAVITY, ...	38
LEVERS AND PULLEYS, ...	41
BREAKING STRENGTH OF A WIRE, ...	50
DEFLECTION OF BEAMS—CANTILEVERS, ...	52
DEFLECTION OF BEAMS—BEAMS SUPPORTED AT BOTH ENDS, ...	58
TRUSSES, ...	60
THE INCLINED PLANE ; FRICTION ; WORK AND ENERGY, ...	65
COMPOSITION OF MOTIONS ; VELOCITY ; ACCELERATION, ...	73
Falling Bodies, ...	78

TABLE OF CONTENTS.

	PAGE
PHYSICAL MEASUREMENT, ...	1
Units and Standards, ...	1
Direct Measurement, ...	2
Error, ...	2
Sources of Error, ...	2
Deviation, ...	3
Determinate and Indeterminate Errors, ...	4
Mistakes, ...	4
Distribution of Deviations, ...	4
Significant Figures, ...	5
DISCUSSION OF OBSERVATIONS UPON RELATED QUANTITIES, ...	6
Plotting Curves, ...	7
INSTRUCTIONS FOR NOTE-BOOKS, ...	10
MENSURATION—LENGTH, ...	12
MENSURATION—VOLUME, ...	17
MENSURATION—WEIGHT, ...	23
COMPOSITION OF FORCES, ...	26
PARALLEL FORCES, ...	31
CENTRE OF GRAVITY, ...	38
LEVERS AND PULLEYS, ...	41
BREAKING STRENGTH OF A WIRE, ...	50
DEFLECTION OF BEAMS—CANTILEVERS, ...	52
DEFLECTION OF BEAMS—BEAMS SUPPORTED AT BOTH ENDS, ...	58
TRUSSES, ...	60
THE INCLINED PLANE ; FRICTION ; WORK AND ENERGY, ...	65
COMPOSITION OF MOTIONS ; VELOCITY ; ACCELERATION, ...	73
Falling Bodies, ...	78

	PAGE
THE PENDULUM, ...	80
FLUID PRESSURE, ...	83
DENSITY, ...	89
SPECIFIC GRAVITY—SPECIFIC GRAVITY BOTTLE, ...	91
SPECIFIC GRAVITY—HYDROSTATIC BALANCE AND HYDROMETERS, ...	95
GASES ; THE BAROMETER ; PUMPS, ...	103
HEAT, ...	115
SOUND—VIBRATIONS OF STRINGS, ...	124
LIGHT—PHOTOMETRY, ...	129
LIGHT—REFLECTION AND REFRACTION, ...	132
MAGNETISM, ...	137
APPENDIX—APPARATUS, ...	141

PREPARATORY PHYSICS.

PHYSICAL MEASUREMENT.

PHYSICAL measurement consists in finding the numerical magnitude of some physical quantity. The results must be expressed in terms of some unit of the same kind. As a basis for the fundamental units we must have some natural quantity, as the mean Units and standards.

solar day, in the case of the standard of time ; or a wholly arbitrary quantity may be chosen, as in the case of the standard of length. For each of these units of the latter class there exists some one standard which is inaccessible except for the purpose of comparison, the units which are used in actual measurement being copies made in a more or less indirect manner. For example, the standard of length, according to the system which we use, is the distance between two rulings upon a rod of platinum kept carefully from injury and never used for actual measurement of length ; the standard of mass is a piece of metal, kept also with great care, and used only for comparison with copies of itself. Some of the units of time employed are the year, hour, minute, second, etc. ; that is, multiples or submultiples of the standard. Similarly, we have copies of the standard of length ; and the units of length which we employ—the kilometre, centimetre, etc.—are multiples or submultiples of these and thus of the standard. Evidently the scales and weights which we use in actual work in the laboratory have been compared only indirectly with the standards, and some comparisons have been made with

much less care than others. In undertaking quantitative measurement, therefore, we have no right to assume that our weights and our measuring scales are correct. When any considerable accuracy is required, we must compare them, as carefully and as directly as may be, with the standards.

The units of mass, length, and time are taken as fundamental units. For mass and length, these are, as we have seen, material standards; the unit of time is a certain definite part of the length of the average solar day. Other units exist as matters of definition only, expressed in terms of these fundamental units of mass, length, and time.

In practice, the measurement of any quantity whatever is reduced to observations upon some length, and its comparison with some unit of length.

Direct measurement consists in the comparison of the unknown quantity with our arbitrary unit, as in measuring length, mass, or time; and all results, however indirect, must be reached by the use of values which have been obtained by direct measurement.

If our powers of observation were perfect and our units absolutely accurate copies of the standards, one such direct comparison would suffice to establish the true value of the unknown quantity. If these two conditions are not fulfilled, there will be a difference between the observed value and the true value. This difference is called the *error* of the observation. Let us see what are the sources of error in direct measurement.

One source of error is, as we have seen, the inaccuracy of our weights and scales. Other sources exist in more complicated instruments. Some of these errors may be found by comparison or otherwise, and proper correction may be made. Another source of error lies in the lack of skill on the part of the observer in making his observations. It will be found, for example,

if a certain distance is to be measured, say within one per cent.—that is, the result obtained must not differ from the true value by more than one one-hundredth of its amount—that successive measurements do not give the same result. They may differ considerably among themselves. Want of delicacy, rigidity, and other defects of instruments cause similar errors. These errors it is not possible to correct for exactly, as there is no way of finding their magnitude which does not involve similar errors. Experience has shown that the best method of eliminating the *errors of observation*, as these errors are called, is to make a large number of observations and to take the *arithmetical mean* or the average.

Suppose a series of such observations has been made, and that a_1, a_2, a_3, a_4 , etc., are the successive values found for the quantity, and that R is its true value. Of the observed values, it may be that no two are alike, or there may be some agreements; but it is not likely that any of them is the same as R . Even if one of them were correct, how should we know which it is? If we know the value of R , we can find $a_1 - R = e_1$, the *error of the first observation*. But if we do not know the value of R —and if we do know it, the measurements are not necessary—we cannot find the value of the error. We must select, therefore, a value which most probably represents the true value, R ; and the most probable value is the *arithmetical mean* or average of the observed values.

We have assumed that all the observations are equally reliable. If they are not, some method must be found of giving a numerical measure of their reliability. In our work, however, we shall always assume that the observations have equal weight.

If the *mean* of the observation is A , the observations will each differ from the mean by a quantity which is called the *deviation* of the observation. Thus **Deviation.**
 $a_1 - A = \delta_1$ is the *deviation* of the first observation. This,

however, is not equal to the *error*, e , unless $A = R$. The *deviations* are *not* the *errors*.

In any given work the number of possible sources of error is very great. The effects of some of these may be **Determinate** errors. determined and measured and the process of measurement so arranged as to prevent them or allow of their *correction*. Such errors are said to be *determinate*, and their effects may be eliminated to a sufficient degree. They can seldom or never be wholly eliminated. Errors which cannot be thus corrected for are called *indeterminate*.

Mistakes are the result of confusion or inattention. Setting down a result in the wrong column, taking a wrong scale-reading, or using a wrong number are mistakes. **Mistakes.** *Mistakes* are *not errors*, as we have used the term. An observation which certainly contains a mistake should be discarded; but the greatest care must be used in deciding to discard an observation. It is allowable only after the strictest examination. In case of doubt it is preferable to discard the entire set and repeat.

Experiment has shown that in the general case of a large number of observations small deviations are more frequent than large ones; very large deviations occur very seldom; and observations differing from the mean by a given amount are equally frequent on either side of the mean. **Distribution of deviations.**

These statements apply strictly only when the number of observations is very great; and as the number diminishes this distribution is departed from more and more widely. If there are comparatively few observations, say not more than ten or twenty, the retention of an observation which differs very greatly from the others, even if it contains no mistake, would produce an undue effect on the mean. The question of the retention or the rejection of a discrepant observation is therefore best left to the judgment of the observer, and his judgment must be exercised in an entirely impartial manner.

In each observation on the value of the unknown quantity, we can usually be certain of the correctness of all the significant figures except the last ; and the last we can assume to be approximately correct. In taking the mean we extend our certainty one place farther ; and the mean should therefore contain one more significant figure than each observation if there are ten observations.

Significant figures.

Significant figures are those figures, in a number, which denote actual values found. They indicate the precision to which the work has been carried. They are not necessarily all digits, even in the last place ; for if the last figure, in the number expressing a value, is one more than 9, the decimal notation requires that the 1 of the figure 10 shall be carried back and added to the preceding place. Neglecting the 0 in the last place would indicate that no value had been found for that place. In the case supposed, this would not be true ; for the value found for that place was 10. The example will make this clear.

Suppose we are measuring a distance which is about 99 centimetres. Let our observations, expressed in centimetres, be as follows :

99.02	98.96
99.05	98.99
99.01	99.03
98.95	99.98
99.00	98.97
Total.....	989.96
Mean.....	98.996

Each observation then contains four significant figures, and the mean contains five. We are sure of the first three places in each observation, but not of the fourth ; and we may be pretty sure of the first four in the mean, but not quite sure of the fifth. In making calculations from such a

mean we must be careful to use only so many significant figures, in all our partial results and in the final result, as are justified by the measurements. There are rules for determining these matters which we are not yet prepared to take up; but we can use judgment as to the retention of significant figures, and "avoid waste labor and a delusive or ludicrous display of figures on the one hand, and on the other insure to the computed result all the accuracy to which it is entitled by the data." [Holman.] If the mean, in our example, had been 99.000 instead of 98.996, we should retain the three zeros as significant figures, showing that the measurements had been carried to that degree of precision. A neglect of these considerations is one of the most common faults of the student, even when somewhat advanced.

DISCUSSION OF OBSERVATIONS UPON RELATED QUANTITIES.

There are many cases in which observations are made simultaneously upon two quantities which vary together and which are related to each other. Suppose, for instance, we have a quantity of water heated to the boiling point, and then placed in a room kept at the freezing point, and we wish to find the rate at which the water cools. We must observe two quantities together: time and temperature. For this purpose, we place a thermometer in the water, and read its indications at equal intervals of time; or we may read the time at equal intervals of temperature, or at convenient intervals. The water finally cools to the freezing point, and we have two columns of observations related to each other in pairs. The most convenient and ready way to investigate the relation of one of these varying quantities to the other—and it is the relation we want to find—is to construct, from their different values, a curve. The method of doing this is as follows: Any numerical magnitude can be represented by the length of a line. For

example, if our thermometer read 100° we can represent that value by a distance of 100 units, choosing whatever unit we find most convenient. And if the value of the time, when the thermometer reads 100° , is 1 minute, reckoned from any convenient starting point, such as the beginning of the experiment, we can represent that value by a distance of 1 unit, choosing whatever unit we wish, not necessarily the same as the unit chosen for representing the temperature. Now how can we show, by these two distances, the relation between the two quantities? If we have a piece of cross-section paper of suitable size, the distance representing time can be laid off horizontally, and the distance representing temperature vertically, from some one point chosen as reference point, or *origin*, as it is called. The lower left-hand intersection of the ruling is usually chosen for the origin. Then follow the lower horizontal line for one unit, and we have the time distance. From this point, follow a vertical line for one hundred units, and the point so found is the point which represents the two related values of time and temperature.

Plotting
curves.

Origin.

The horizontal line through the origin is called the *Axis of X*, and the vertical line through the origin the *Axis of Y*. Distances along the axis of *X* are *abscissas*, and distances along the axis of *Y* are *ordinates*.

Axes.
Co-ordinates.

The next pair of values of time and temperature is plotted in the same way. Suppose the time is 2 minutes, and the temperature 95° . We shall then have a record point 95 units above the axis of *X* and 2 units from the axis of *Y*.

In this way we find the whole series of points representing the successive pairs of values of time and temperature, and through these points we draw a smooth curve. If a *smooth* curve cannot be so drawn as to pass exactly through all the points, which it seldom can, we draw it in such a way as to pass through the average path of the points, thus giving directly the *mean* of the observations. There should

be, at all portions of the curve, as many points above as below it. The horizontal or vertical distance of the point from the curve represents the *deviation* of that observation.

The best and easiest way to plot a curve in practice, as given by Holman, is in substance as follows: Start with a piece of plotting paper of suitable size (the page of the notebook, for our work, or if necessary two pages). The paper is ruled in tenths of an inch, with every tenth line heavier. For special cases, other spacing and other sizes may be used. Select a scale of abscissas such that the points when plotted will stretch from one side to the other of the sheet, or of a convenient part of it. Then number every tenth unit (or other convenient number) along the bottom of the sheet. Select a scale of ordinates such that the points shall also stretch across the sheet vertically for about the same distance as horizontally, and number the tenth units vertically. This numbering is an aid to plotting, and is essential to clearness. This will bring the curve as nearly as possible at 45° to the axis, in general. If the scales for both coördinates are the same, the plot will have its normal form; if they are unequal, it will be distorted. The latter is generally the case, and is not only not a disadvantage, but is necessary to the best working conditions. It is not always necessary or best that the origin of coördinates should appear on the sheet. Certain scales are very awkward and should be avoided; for example, 1 inch to 3 units, to 7, or 15 units, etc.; while such as 1 inch to 2, 5, 10, 20, 50, or 100 units, etc., are convenient. The scale of 1 to 4 is not so bad as the first set mentioned, but is less convenient than those contained an even number of times in 10. The data must never be modified, before plotting, by multiplying by some number with the idea of thus obtaining a more convenient scale. Such changes only lead to confusion or inconvenience, and the desired result can always be reached much more easily by suitably numbering the axes.

In locating a point, use a moderately hard, sharp pencil,

or drawing pen. Read off the abscissa and ordinate from the data. At a height about equal to the ordinate, draw a short, fine vertical line, whose horizontal distance is exactly equal to the value of the abscissa. Then draw across this a short horizontal line at a height exactly equal to the ordinate. This will give an intersection located by a +. These points must always remain clearly indicated on the finished plot.

To draw in the curve, use a pen—a drawing pen is best—and make only fine lines. The plot usually consists of a number of points more or less regularly distributed. If a smooth curve or a straight line is drawn to represent them, it must pass among the points in such a way as to leave the deviations (*i. e.*, the vertical or horizontal distances of the points from the line) distributed according to the law of deviations, as already stated. There should thus be about as many points on one side as on the other of the line; the sum of deviations on each side should be always the same, and should be as small as possible; and these rules should be followed throughout the whole length of the line; for example, the points should not lie mainly on one side at one end, and on the other side at the other end. If a straight line is to be located, its best direction may be most readily found by stretching a black thread, and moving this over the plot until the points appear to have the best distribution about it.

INSTRUCTIONS FOR NOTE-BOOKS.

The note book required consists of about 50 leaves, or 100 pages, ruled in cross-section to 1-10 of an inch. The size of the ruled page is 6 × 8 inches, and the leaves are bound permanently in a pair of stiff covers. The student's name, with his year and section, must be put upon the right-hand upper corner of the cover.

Place the name and number of the experiment at the top of the right-hand page and the date just below. Always begin a fresh page for a new experiment. Do not give descriptions unless they are called for; and when you give a description, make it brief and clear.

Enter all observations *at the time they are taken*, and the results computed from them, on the *right-hand page only*. The *original records* must be made in the book, and not copies. Take plenty of room and never crowd your work. Do not use an eraser. If you desire that entries made should be omitted draw a line through them, and they will not be regarded. In all cases, try to have your book neat, and cultivate order in arrangement.

The whole of the work of computation is to be carried out on the left-hand pages, opposite the entries for the experiment for which it is made. From these computations, the main steps and the results are to be entered on the right-hand pages. Use no loose papers in your work, but put on the left-hand pages of the note-book any work for which you would use the loose papers. It is very often a great saving of time and trouble to be able to refer directly to the actual arithmetical operations to discover a mistake.

The note-books are to be handed in to the instructor from time to time, as he shall require.

Curves should be plotted on *right-hand pages only*, as they form a portion of the final records. In each case of curve plotting follow the directions already given.

In all your work, take plenty of room, and remember that notes on experimental work should be easily intelligible to others, in connection with the instructions.

EXERCISE I.

MENSURATION—LENGTH.

There are several methods of making a direct measurement of length. When possible, the scale may be applied directly to the distance to be measured. In using a measuring rod in such a way, as, for instance, in measuring the distance between two points, do not attempt to place the end of the rod or any particular mark upon it, in coincidence with one of the points. You can never do this accurately, while you have a delusive sense of accuracy in the observation. Place the rod at random over the distance, only taking care that it covers the distance, and that both points come just at the edge of the scale. Be sure also that the scale itself is next to the points. If the rod is rectangular, and so placed that the scale is on top, there is a considerable space between the scale and the points. The small difference in the angle of the line of sight, which is unavoidable, makes a considerable difference in the readings. The scale should be on one of the sides, and should be brought directly against both of the points. Having placed the scale properly, read the position of each of the points limiting the distance. Suppose, for example, that we are measuring the distance between two points, using a metre-stick, and that the first five sets of readings are as follows; the readings being in centimetres :

Reading, 1st Point.	Reading, 2d Point.	Difference.
22.48	62.46	39.98
15.30	55.52	40.02
20.32	60.33	40.01
41.73	81.77	40.04
00.39	40.42	40.03
Total.....		200.08
Mean		40.016

Evidently, placing the stick at random, as we have, and in a new position at each reading, we do not think, in advance, just what the second reading is likely to be ; and can therefore more probably make our observations without bias. If we had tried to set the stick at some particular line each time, there would have been a strong temptation to make the reading of the second point such as to give the same difference for each observation.

Taking the mean of the five observations—which are too few—we find the ‘most probable value for the distance we are measuring. A careful setting of the scale would probably have induced us to think it was just 40 centimetres, and we might have made each reading such that all the differences were the same ; whereas the value of the mean, 40.016, is really more accurate if the scale is correct. In careful work the scale used should be compared, either before or after measurement or both, with the best standard available.

To find the deviation of each observation, we subtract the mean from each observed difference, and place these remainders in another column in the same table. The completed table would then be as follows :

Reading, 1st Point.	Reading, 2d Point.	Difference.	Deviation.
22.43	62.46	39.98	— .036
15.50	55.52	40.02	+ .004
20.32	60.33	40.01	— .006
41.73	81.77	40.04	+ .024
0.39	40.42	40.03	+ .014
Total.....		200.08	.084
Mean.....		40.016	.0168

The sum of the negative deviations is, of course, equal to the sum of the positive deviations, and the absolute magnitude of the mean deviation is the average of the absolute values of all the deviations.

When the two points, whose distance from each other we wish to measure, are so situated that a scale cannot be applied directly, there are several devices for overcoming the difficulty. If the distance is small, a pair of microscopes, or a single microscope, may be used. The centre line of each microscope, usually marked by the intersection of cross-hairs, is brought just over a point. Then, if the microscopes slide on a scale, their distance apart can be read off, as in the example given. If this is not the case, the microscopes may be maintained in position while a standard scale is substituted for the unknown distance. Then the difference between the readings on the standard scale gives the value of the unknown distance. This is one of the best methods of comparing scales together, and is a very simple method, too.

If the unknown distance is so situated that microscopes cannot be used, it may be measured in a similar way, by the use of telescopes. Of course either the microscopes or the telescopes, if they slide on a scale, must be kept exactly parallel. If the distance is found by substitution of a standard scale in the same place, the direction of the microscopes or telescopes may be any whatever, so long as it does not change during the substitution.

The same thing may be accomplished by a single microscope or telescope sliding on a scale. In such a case the cross-hairs are brought just into line with one of the points, and the position of the telescope read from the scale. The telescope is then moved until the cross-hairs are in line with the second point, and this second position also read off. The difference between the two readings gives the required value. Of course, in this case also, the centre line of the telescope, in its second position, must be exactly parallel to its direction in its first position. This is the principle upon which the instrument called the cathetometer is based. It is an instrument employed for the measurement of vertical distances, and the direction of the telescope is adjusted by means of the spirit level.

The latter methods are not adapted for our present use, but it is best to understand the principles of all these methods before undertaking any.

EXPERIMENT.

Apparatus.—App. A : metre stick ; copper wire ; file ; cutting pliers.

Cut, from the coil of wire, a piece about 15 centimetres longer than the board of App. A. Make, in one end of the wire, a loop about the middle screw of the clamp, making fast in the usual manner, by twisting the free end of the wire about its main portion. Pass the other end of the wire through the hole in the pin at the other end of the board. Using the wrench, turn the pin until the wire is straightened out. When the wire sounds a very low note on being plucked with the finger, it is sufficiently stretched. Place in position under the wire the two bridges, as far apart as the apparatus will allow.

Then measure, according to the method first described, the distance between the centres of the bridges. Every reading should be made to the tenth part of the smallest division on the scale—in this case, to the tenth part of a millimetre. The tenths may be estimated by the eye—very easily after a little practice. Make ten sets of readings, and enter them in a table in your note-book, as follows :

Reading, 1st Point.	Reading, 2d Point.	Difference.	Deviation.

Having completed the measurements, mark the wire strongly, with a sharp file, immediately over the centre of each bridge. Remove the bridges, slacken the wire, and cut at the marked points.

In handling wire in this way, take care that you are so

placed that if the wire should break no injury to yourself will result. Hard wire, when it breaks suddenly, may spring back, and the sharp, broken end will cut where it strikes. Copper wire is less likely to recoil than steel or spring brass.

Twist into a small coil the piece of wire cut out, and reserve it for use in Exercise III.

EXERCISE II.

MENSURATION—VOLUME.

The value of an unknown volume may be found, if the body is of regular form, from measurement of its linear dimensions. There are many cases, however, in which the calculation of volume from the dimensions, even if they can be measured, is long and tedious ; and in which it is much easier and fully as accurate, to find the volume in some other way.

As a liquid will take the form of any vessel in which it is placed, its volume is very easily measured ; and one of the easiest methods of finding the volume of a body of an irregular shape is by the direct measurement of the volume of water which the body displaces. To measure the volume of a liquid, we use graduated glasses or, more briefly, "graduates." A graduated glass is usually cylindrical, and has etched upon it a scale which shows the volume of a liquid whose surface just reaches that line at which the reading is taken. There are other shapes of graduated glass, but the cylinder is most common. The burette is a particular form, having an opening, provided with a stop-cock, at the bottom, and often graduated both ways—that is, from the lowest mark up to the top, as well as from the top downward. The smaller graduates, on the metric system, have a scale reading to single cubic centimetres, or even to parts of a c. c. The larger graduates read only to 10 c. c. or even 100 c. c. Burettes generally read to 1-10 c. c. and have every tenth line numbered ; so that, between two adjacent numbered lines, there is contained, in the tube, just one cubic centimetre.

The surface of any liquid contained in a vessel is not perfectly flat, but is curved either up or down where it touches the sides. Most liquids will rise at the sides, producing what is called a *concave meniscus*—the curve of the surface is called a meniscus; but some, such as mercury, will fall at the sides, producing a *convex* meniscus. In reading the height of any liquid in a tube or a vessel, do not try to read the position at the top of the liquid, where it touches the glass. It is spread out so thin there that it is impossible to tell just where the liquid ends. It is very easy, however, to read the position of the middle point of the curve, where it just touches the horizontal. Looking through the glass, horizontally, the curve of the surface seems to just rest on the line which shows its volume. It is most necessary to look horizontally through the glass, and to have the glass perpendicular, for, as the graduations are on the outside of the glass and the point from which the reading is taken is at the middle, looking either up or down toward the middle would give a wrong reading.

If we have a quantity of liquid in a graduate and drop into it any body whose volume we wish to find, the level of the liquid will rise in the glass, by an amount just equal to the volume of the body. All that we have to do, therefore, is to read the scale before and after dropping in the body. The difference is the volume required.

Or we may pour from a graduate—or run from a burette, which is better—into a glass, sufficient water to fill it up to a given mark. Then empty the glass, dry it, put in the body and fill up to the same mark again. There will have been less water necessary, in the second case, to fill the glass to the mark, by an amount just equal to the volume of the body. Either of these methods is sufficiently close for most purposes, but a burette should be used in preference to other graduates, whenever possible, as it is graduated with much greater care. When it is necessary to find a volume with any considerable accuracy, no such methods as those described will

answer. The volume of the body must be found by the *weight* of water displaced. This is a quantity which can be much more closely measured than the volume can be directly.

In using a burette, it is not necessary, nor is it best, to attempt to fill it exactly to any given mark. The remarks in regard to the use of measuring rods, in the first exercise, apply to this case very exactly. Read the position of the top of the water—the convexity of the meniscus—run out what is needed, and read the level again, allowing a sufficient time for the water to run down the inner walls of the tube. Every reading must appear in the note-book. If more water is needed than the burette will hold, run out what is in it, taking care not to let the water fall below the lowest mark. The difference of the readings gives the amount run out. Fill up the burette again, take the upper reading, run out what is wanted, and read again. The sum of the differences, then, is the total volume of the water.

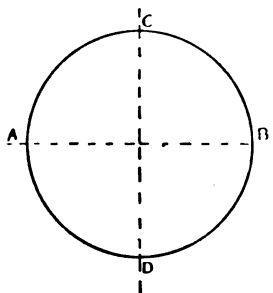
EXPERIMENT.

Apparatus.—Graduate cylinder; burette; metre stick; two metal cylinders.

Take the two metal cylinders furnished you for the purpose, and find the volume in each of the three ways described: 1. By calculation from measurement; 2. By displacement, volume of water constant; 3. By displacement, total volume constant.

By method 1. Measure the diameter of the cylinder at each end, according to the directions for the measurement of length. In finding the diameter of a wire or cylindrical rod, if the wire were truly cylindrical throughout, it would, of course, be sufficient to find the most probable value for the diameter at any one point. It is practically impossible, however, to draw wire or to roll a rod that shall

be truly cylindrical. The cross section may be at some points oval, or elliptical, and at other points circular. It is best, therefore, to find values for two diameters at right



angles to each other. This will enable us to find a very close approximation to the true diameter by taking the mean of the values for these two directions. Thus, if we are measuring the diameter, at the cross-section shown in the sketch, we should make, say, three measurements each of the diameters *AB* and *CD*. Then the

mean of these six measurements would give us a value for the diameter of the rod at that cross-section sufficiently near the truth.

In measuring the diameter of the cross-section with a scale, the scale should be placed upon the end of the cylinder, and moved over it until the greatest chord is found. This will be the diameter.

Find the mean of six measurements, taken in that way, across each end of each of the metal cylinders. Then make five measurements of the length of the cylinder, and from the mean diameter and mean length calculate the volume. The volume of a cylinder is found as follows, where *d* is the diameter, and *l* is the length.

$$\text{Volume} = \frac{\pi d^2 l}{4}$$

π is the ratio of the circumference to the diameter of a circle and may be taken as 3.1416. Be sure that all quantities are expressed in the same units. The centimetre is the best unit for the purpose. Then the volume will be expressed in cubic centimetres. Arrange the results in such a form as this :

Number of Cylinder.	Diameter.	Mean Diam.	Length.	Mean Length.	Volume $\frac{\pi d^2 l}{4}$

By method 2. Run into the graduate a quantity of water such that when the cylinder is put in, the water will not rise above the highest graduation. Read the volume, to one tenth of the smallest division. Drop in the cylinder and read again. The difference between the two readings is the volume of the cylinder, in cubic centimetres. Arrange results as follows :

Number of Cylinder.	1st Reading.	2d Reading.	Difference.	Mean Volume.

Make three measurements of the volume of each cylinder, in this way.

By method 3. The graduate is to be used, in this case, not to read volume, but merely to furnish a mark for reference. Fill the graduate to some chosen mark, using the burette, and finding the volume run out of the burette according to the directions already given for its use. Empty the graduate and dry it. Place the cylinder in the graduate and fill again, from the burette, to the same mark as before. The difference between the volumes of water run

into the graduate in the two cases gives the volume of the cylinder. Arrange results as follows, making but one determination for each cylinder :

Number Cyl.	Water alone in Graduate.			Water and Body in Graduate.			Vol. of Cyl.
	1st Bu. Rd.	2d Bu. Rd.	Dif.	1st Bu. Rd.	2d Bu. Rd.	Dif.	

Having made the determinations for each method and each cylinder, summarize the results in a table, as follows :

Number of Cylinder.	Volume.		
	By 1st Method.	2d Method.	3d Method.

Which method do you consider the most accurate, and why ?

EXERCISE III.

MENSURATION—WEIGHT.

Weighing, by the use of a balance, is really a comparison of masses. It consists in balancing the attraction between the earth and one mass against the attraction between it and another mass. When these attractions are equal, the masses are equal.

Weighing by means of a spring balance, or dynamometer, consists in balancing the attraction between the earth and the unknown mass against the elastic force of the spring. The amount of elongation of the spring measures the weight of the unknown mass. A spring balance, however, must be calibrated—that is, the value, in weight, of a given elongation found by noting the elongation of the spring when a known mass is attached. Spring balances, or dynamometers, are easier to use, but less accurate, than the equal arm balance, and are suitable for rough work only.

If the balance is properly adjusted, the beam should be horizontal when it is at rest, and the index should point to the zero of the narrow scale on the front of the column. When the difference from this zero is but slight, the reading may be taken as the point of rest; but if the index is very far from the zero, an adjustment should be made by turning the little milled nut on the end of the beam.

In finding the weight by the equal arm balance, place the body to be weighed in the left-hand scale-pan. Then, beginning with the larger weights, place weights in the right-hand pan until the pointer swings over the same number of divisions on each side of the point of rest. Never handle

any of the weights. They should be touched only with the forceps. It is not best, with the balance and weights used in this work, to weigh to one milligramme.

When balance is obtained, add up the weights in the pan and note the total. Count up the vacant spaces in the box, and note the total. Then take the weights from the pan, one by one, the larger weights first, adding them up as they are taken off. See that this total corresponds with the numbers previously obtained. All weights should be written down in terms of the gramme. That is, 50 grammes, 4 decigrammes, 3 centigrammes, would be written 50.43 grammes.

EXPERIMENT.

Apparatus.—Balance ; box of weights ; the coil of wire used in Exercise I. ; the metal cylinders used in Exercise II. ; three unadjusted brass weights, of masses of about 200, 100 and 50 grammes, respectively.

1. Weigh the coil of wire, and record its weight. Knowing its length and weight, compute

(a) The weight of 1 kilometre in kilogrammes.

(b) The diameter of the wire, assuming that 1 cubic centimetre of copper weighs 8.89 grammes. The other data necessary for this computation are contained in Exercise II.

2. Weigh each of the metal cylinders, recording the weight opposite the number, and see that the total of the two separate weights checks the value found by weighing them together. Record as follows :

Number of Cylinder.	Weight.
A	
B	
A+B	

3. Take a beaker which will contain as much as 40 cubic centimetres. Weigh it carefully, and record its weight. Run into it, from the burette, any small quantity of distilled water, noting the volume carefully. Weigh the beaker with the water in it and record again. Repeat this operation with three different volumes of water, using, first, about ten cubic centimetres; second, about twenty-five cubic centimetres; third, about forty cubic centimetres. Pour out the water and dry the glass after each weighing. The results should be recorded in the following form:

1 Bu. Rd.	2 Bu. Rd.	Differ. = Volume.	Wt. Beaker.	Wt. Bkr. + Water.	Differ. = Wt. Water.	Wt. (Grms.) Vol. (Cu. C.)

If the water were at the temperature of 4° C. (about 39° F.) and the measurements were sufficiently precise and accurate, the value of $\frac{\text{weight}}{\text{volume}}$ would be exactly equal to 1.

With the conditions met, the value of this quotient will probably be somewhat less than 1.

4. Weigh carefully each of the three brass weights, and record their respective weights in your note-book, for future reference. If the values found are greatly in excess of the assigned values of 200, 100, and 50 grammes, respectively, a rough adjustment may be made by boring out a small quantity of the metal. The final value of the weight should, in each case, be recorded.

EXERCISE IV.

COMPOSITION OF FORCES.

Force is anything which changes, or tends to change, the state of rest or of uniform motion of a body.

Two forces are said to be equal, when, if they act on a particle in opposite directions, the particle remains at rest.

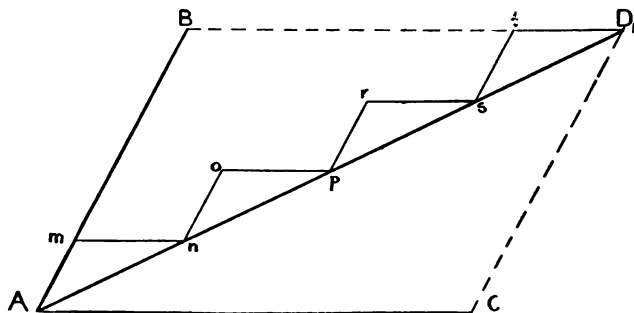
We know all that is necessary about a force when we know its magnitude, its direction, and its point of application. Evidently, then, we can represent a force completely by a straight line drawn through the point of application of the force. For the direction of the line will represent the direction of the force, and the length of the line may be made the same number of units of length (any desired unit) as there are units of force in the given force.

If one body lean against or rest upon another, each body exerts force at the point of contact. Such a force is called a *reaction*. The force that the first body exerts on the second is just equal and opposite to the force the second body exerts on the first ; that is, the *action* is equal to the *reaction*. For example, if a book rest upon a table, the downward force exerted by the book on the table is just balanced by an upward force exerted by the table. If this were not so, there would be some force remaining, and this would necessarily produce motion.

When any number of forces (two or more) act upon a body, and are so arranged that the body remains at rest, the forces are said to be in equilibrium.

If a body has two forces acting on it at the same time, in

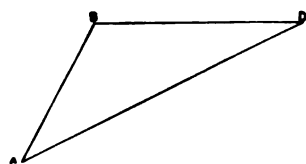
different directions, the tendency is for it to move in two directions at once. What will actually happen? Let us suppose that first one force and then the other acts for a short time. If we divide the forces into an equal number of parts, and let these parts of each act alternately, they will cause the body to move, first one way and then another. If the forces are divided into four parts each, the body will be given motion along the line *AmnoprstD*. The direction of the body, from *A*, is then *AD*. If we conceive the times during which these forces act alternately to become smaller and smaller, the path will become more and



more nearly coincident with the straight line, *AD*; and if the original forces *AB* and *AC* had acted simultaneously, the body would have moved in the direction *AD*. This, then, is the direction of the *resultant* of the two forces *AB* and *AC*; and the magnitude of this resultant is the length *AD*. A *resultant* force, therefore, is a single force which can be substituted for any number of separate forces, and which, acting alone, will produce the same effect as all the forces acting together.

It is not to be understood that, in the example above, the body will actually move to the point *D*, under the action of the forces *AB* and *AC*, and there stop. The body keeps on increasing its motion so long as any unbalanced force acts upon it, and can only be stopped by the exercise of an

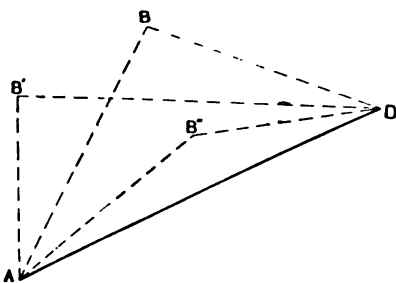
equal force acting in the opposite direction. AD , however, represents, in magnitude and direction, the effect of the



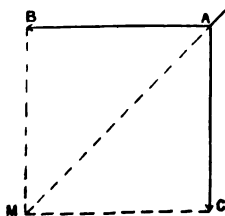
combined action of the two forces. A consideration of the construction of the figure will make it plain that AD can be found directly by constructing a parallelogram, on AB and

AC as adjacent sides, and drawing the diagonal from A to the opposite corner. Or, draw first one side AB , then from its end B draw the other to D . Connecting the ends A and D , gives the third side of the triangle, AD , the resultant.

Evidently, as we can find the resultant of two forces by constructing the triangle, so we may proceed in the reverse



direction and consider any single force as the resultant of two other forces, which, with the first, form a triangle. If we have a force of pairs of forces combined effect the single force, forces are called AD given, any number may be found, whose is the same as that of AD . These pairs of components.



If, then, we have three forces acting on a body, and that body remains at rest, the forces must be in equilibrium. Any one of the forces, therefore, must be exactly equal in magnitude, and opposite in direction, to the resultant of the other two.

For, take any two, as AB and AC , and construct their resultant, AM . The effect of the force AM

is the same as that of AB and AC together, and the body must move unless AD is exactly equal and opposite to AM .

EXPERIMENT.

Apparatus.—Two App. A : weights ; two cords with hook at each end.

Two students should work together on this experiment.

1. Place two of Apparatus A so that the ends carrying the pins project over the edge of the table. Hang a pulley upon each pin. Pass the longer of the two cords over both pulleys. It should be long enough to hang down a foot or so beyond each pulley. Hook one end of the short cord upon the longer cord, between the pulleys.

Hang a weight on each free end of each cord, and allow the cords to assume a position of equilibrium. For example, hook a one-hundred gramme weight to each end of the long cord, and a fifty gramme weight to the free end of the short cord. Allow them to come to rest, making sure that the pulleys turn freely. The direction of each cord from the point of junction should then be noted as follows : Place the note-book behind the cords and bring it near until the cords just clear the page. Then mark carefully the position of the intersection by a dot. Keeping the book carefully in position, mark the direction of each cord by another dot placed just under each, an inch or two from the intersection. At each dot note down the weight hanging on that cord. Remove the book, change the weights, and repeat the manipulation, allowing plenty of room on the note-book page for each. Two on a page is sufficient. Apply unequal as well as equal weights at the ends of the long cord.

Having made four such records, with different weights in each case, the results are to be worked out as follows : Using a hard pencil and a straight edge, connect the point of intersection, in each set of dots, with each of the other points. Each of these lines shows the direction of the force acting along the corresponding cord, outward from the point of in-

tersection. To represent the magnitude, lay off, from the intersection, as many units of length as there are units of force acting on that cord, as expressed by the number near the dot. Any unit may be chosen which is suitable for the space available on the page. Having thus represented the direction and magnitude of each of the forces, choose any two, say the upper two in each set, construct carefully the parallelogram of forces, and find the resultant. If the work is all performed with care, and the friction of the pulleys has been very small, this line will be a continuation of the line representing the third force. Measure the length of this resultant, in the units chosen for representing the forces, and note it down at the end of the resultant. It should, of course, be the same as the length of the line representing the third force. This construction must be performed for each set of forces with as much care as may be, and no "fudging," or intentionally inaccurate drawing, to make the line take its proper direction and length, will be allowed. Results must in all cases be found as accurately as possible from the experimental data, bearing in mind always the possible sources of error.

2. Take three spring balances, hook them in line, and hang some weight at one end of the last one. Note the reading of each and the weight used. What conclusions do you reach from these results as to the tension throughout the line of balances?

If you are stretching a cord between your hands, exerting a force of ten pounds with each hand, what is the force at any point of the cord?

If one end of the cord is fastened to the wall, and you are exerting a force of ten pounds on the other end, what is the tension in the cord? What is the difference between the two cases?

If you are in doubt as to the answers to these questions, try an experiment, using spring balances and weights, which shall give you an answer. Describe in your note-book, briefly, the experiment, giving results and conclusions.

EXERCISE V.

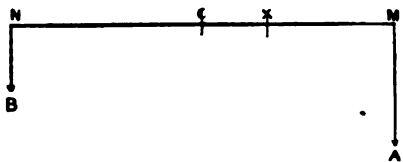
PARALLEL FORCES.

Evidently, if the forces acting on a body act in lines which are parallel to each other, they will have no point of intersection, and their resultant cannot be found by the construction given in the last exercise. If there are two forces only, and they act in opposite directions upon the same point, the resultant will be their difference and its direction will be that of the larger force. If the two forces are in the same direction, the resultant is equal in magnitude to their sum, and acts in the same direction. If the two forces are in the same direction, but applied at different points, the resultant is still equal to their sum, and in the same direction as the two component forces. We see, then, that if a force in one direction be called positive, a force in the opposite direction will be negative, and the resultant will in each case be the *algebraic sum* of all the component forces.

In each of the first two cases there is but one point of application, and hence the resultant must act through that one point. In the last case there are two parallel forces acting at different points. The resultant is equal to the sum of these two, but where shall it be applied? To answer this question properly, we must first consider the effects of the component forces separately.

The effect of the force A , if the body is a straight rod, is to turn the rod about the middle point C , in the direction of A . This tendency to turn is measured by the product of the force A into the distance between its point of application M , and the point C . This product, or $A \times MC$, is called the *moment* of the force A about C . The effect of the force B is, on the contrary, to turn the rod about C in

the direction in which B acts ; and this tendency is measured, similarly, by the *moment* of the force B , or $B \times NC$.



Now, in order that the single force substituted for the two shall be the true resultant, it must be so placed that its tendency to

turn the rod shall be equal to the *algebraic sum* of the effects of the component forces.

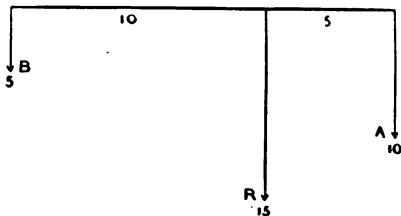
The moment of each force about any other point would be found in a similar way. Suppose X to be the point of application of the resultant. We know that if a force equal and opposite to the resultant be applied at that point, then the whole system will be in equilibrium, and no motion of any sort will take place. Therefore the tendency of one force, A , to turn the rod about the point X , is exactly balanced by the tendency of B to turn it about the same point in the opposite direction ; and the *algebraic sum* of the moments of the component forces about the point of application of the resultant is zero. We have thus fixed the position of the point at which the resultant is to be applied.

$$A. MX - B. NX = 0$$

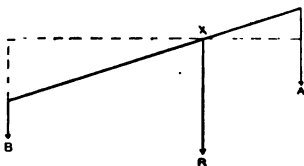
$$A. MX = B. NX$$

$$\frac{MX}{NX} = \frac{B}{A} \text{ or } MX : NX :: B : A$$

For example, if we have two forces of 5 and 10 respectively, applied to a straight rod, the resultant is equal to the sum of the two, or 15 ; and the point of application is distant one-third of the length of the rod from the larger force. That is, the distance is divided in the ratio of 10 to 5, as shown in the diagram.



We have, so far, considered only the case in which the force acts perpendicularly to the rod. If the line of action of the force is not perpendicular to the rod, the product of the force into the distance between the point of application and the point X does not represent the moment. The moment of a force about a given point is the product of the force into the perpendicular



drawn from the given point upon the line of action of the force. As, however, this perpendicular and the rod are divided always in the same proportion, we can, without error, find the point, X , of application of the resultant, in the same way, whether the forces are perpendicular to the rod or not, so long as they are parallel to each other.

We may apply the same principle to any number of forces. The algebraic sum of the moments of any number of forces about any point is equal to the moment of their resultant about that point.

When a rod, suspended from any point of its length, has weights attached to its ends, there are to be considered, not only the effects of the weights, but also the effect of the weight of the rod itself. If the rod be of uniform size throughout its length, its weight may be assumed to act at its centre. Suppose, then, that a light rod, having a weight of 50 grammes at one end, and a weight of 25 grammes at the other end, be suspended in such a way that it just balances. There are three forces acting downward: 50 grammes, 25 grammes, and the weight of the rod (say 5 grammes). If the rod is 1 metre long, and the point of suspension is X centimetres from the larger weight, the moment of the weight of rod = $-5(50 - X)$;

the moment of the weight of 50 grm. = $50X$;

" " " " 25 " = $-25(100 - X)$

The sum of these must be zero, as the resultant must

pass through the point of suspension when the system is in equilibrium.

$$\begin{aligned} 50 X - 25 (100 - X) - 5 (50 - X) &= 0 \\ 80 X - 2750 & \quad X = 34.375 \text{ cm.} \end{aligned}$$

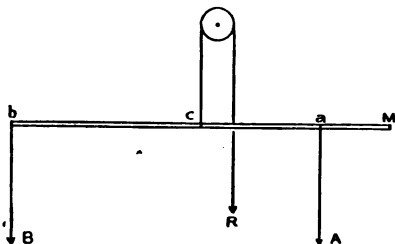
EXPERIMENT.

Apparatus.—App. A ; weights ; deal rod ; cord ; metre stick ; fine spring brass wire.

Two students should work together upon this experiment.

1. Place the App. A so that the brass pin projects over the edge of the table. Hang a pulley upon the pin. Weigh the rod and record its weight.

Pass a cord over the pulley and suspend the rod by its centre from the end of the cord. If the rod does not hang evenly, a slight adjustment of the cord may be made until balance is obtained. Suspend, at one end of the rod, by a cord, in the same manner, weight



B, 50 grammes ; at 20 centimetres from the other end suspend weight *A*, 100 grammes. Make *R* such as to balance the system. Then *R* has to balance *A* and *B* and the weight of the rod. Move either *A* or *B*, but *not both*, along the rod until the system is balanced. This is the principle of the common steelyard. Then measure the distances necessary for the calculation of the moments and compute the moments of *A* and of *B* about the point of suspension. Do these moments fulfil the conditions as they should ; and if not, what is the cause of error ? Record your results in the following form :

Wt. of Rod.	WEIGHTS.						Moments of	
	A.	B.	Wt. of Rod + A + B.	R.	ac.	bc.	A.	B.

Repeat, making $ac = 30$ cm., and record in the same table.

2. Suspend A and B from the *ends* of the rod, and slide the whole system of rod and weights through the suspending loop until balance is obtained. Measure the necessary distances and calculate all the moments. Verify them, remembering that the sum of *all* the moments about the point of suspension must equal zero. Record as follows :

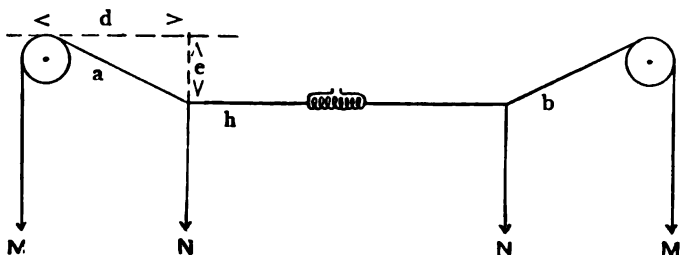
Wt. of Rod.	A.	B.	ac.	bc.	Wc.	R.	A+B+W.	Moments of			Sum of Moments.
								A.	B.	W.	

Repeat, using different values for A and B . Make three trials in all, and record in the same table. Explain briefly the difference between cases 1 and 2 and its effect.

3. Cut from the spring brass wire a piece about thirty centimetres long. Make it into a close spiral spring, by winding tightly around a pencil or glass rod. Leave a straight portion projecting at each end, and bend these ends toward each other until they nearly meet. This spring will serve as a dynamometer. It may be calibrated as follows: Suspend it from the brass pin at the end of App. A, with no weight attached. Measure the distance (parallel with the axis of the spiral) between the ends of wire. Hang upon the lower end of the spring a known weight—one not sufficiently great to produce a permanent “set” in the spring—and measure the distance between

the ends of wire, as before. The difference between these two measured distances is the elongation produced by the weight applied; and the extension may be taken as proportional to the weight for all forces which are not great enough to produce a permanent change of shape in the spring.

Replace the pulleys upon the brass pins. Over each pulley pass a cord, as shown in the diagram, inserting the spring in the central part of the cord.



Hang equal weights, M , M , upon the ends of the cord, as shown, and hang other equal weights, N , N , by cords from points on each side of the spring. The weights M may be 200 grammes each, and the weights N 50 grammes each. Then move the whole system over the pulleys either to the right or to the left, until the cord h , between the weights N , N , is horizontal.

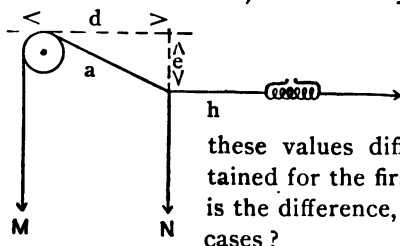
Measure the angle made by the cord a with the horizontal. This should be done by placing a metre stick across the tops of the pulleys and reading the distance d ; then measuring, with another metre stick, the vertical distance, e , from the lower edge of the upper stick to the cord h . By keeping the ratio $\frac{d}{e}$ the same, the angle may be

kept constant. Record these values, and the values of the weights, in your note-book. Find, by measurement of the elongation of the spring, the tension in the cord h . The record of these values is best made by drawing a

diagram and placing under the line representing each cord the value of the tension in that cord. Record the value of each weight used beside M and N in the diagram.

Hang NN from the same point on the cord, move the whole system over the pulleys until the weights NN hang from the centre, and measure the angle as before. Record by means of a diagram, as in the first case. What difference is there, if any, between these two cases?

Remove one of the cords, b , and the weight M . Hold the cord b horizontal, and use only one of the weights N .



Measure the angle, the tension in b , and record all values on a diagram in your note-book. Do

these values differ from the values obtained for the first case, and why? What is the difference, in fact, between the two cases?

Work out carefully, in your note-book, by the parallelogram of forces, the tension in the cord b , in each case, using the values of M , N , d , and e , but assuming the elongation of the spring to be unknown.

You have, in this experiment, a very fair representation of the conditions obtained when two trolley wires are suspended from a single span wire. The weights NN represent the weight of one section of the trolley wires, and the weight M represents the tension in the span wire for the given angle of dip.

EXERCISE VI.

CENTRE OF GRAVITY.

The attraction between the earth and any body is exerted equally upon every particle of the body. There is then, for every mass, an almost infinite number of forces which are parallel, and for which, therefore, there may be found a single resultant. There must be some point within the mass of the body, such that the action would be the same if the total mass were concentrated at that point. That is, the resultant force passes always through that point, in whatever position the body is placed. This point is called, for obvious reasons, the *Centre of Gravity*, and for most purposes the body may be treated as though the whole mass were concentrated at its Centre of Gravity.

If a body be suspended from any one of its points, the action of gravitation, or its weight, will cause it to move until the Centre of Gravity is directly below the point of suspension. That is, the action of gravity and the reaction of the suspending string must be exactly in the same straight line. We see, therefore, that if a body be so suspended, and the line of the suspending cord be continued, it will pass through the Centre of Gravity ; so that we may find the Centre of Gravity by suspending the body from several points in succession and "producing" or continuing the line of the suspending cord. The intersection of these lines will be the Centre of Gravity, and all such lines *must* intersect at the same point.

The "plumb-line" operates on this principle. The "bob" is a small body of considerable mass, attached at the end of the line, and usually so shaped that its apex, or point, comes

directly beneath the suspension. The direction taken by the string shows the line of action of gravity. By this instrument we are enabled to determine the vertical.

If a body suspended as described, and at rest, be drawn aside from its position of equilibrium, it tends to return to that position, for, in the act of drawing it aside, the Centre of Gravity is raised, and as there is nothing to prevent its falling again, the force of gravity will draw it down. A body so placed, at rest, that when slightly moved it tends to return to its former position, is said to be in *stable* equilibrium.

Suppose the body in question to be a ball, or sphere. When suspended, its equilibrium is stable. If, however, the ball be resting on a horizontal surface, a slight motion to one side does not raise its Centre of Gravity. It does not tend to return to its former position, but will stay where it is put. In such a case a body is said to be in *neutral* equilibrium.

If a cone or pyramid be placed with its flat base on the table, it will be in stable equilibrium. It may, with care, be balanced on the apex, and will then be in equilibrium. When it begins to topple over, however, the Centre of Gravity is lowered, and as there is nothing to stop it, it will continue to fall. In such a case, a body is said to be in *unstable* equilibrium. When slightly displaced from the position of equilibrium, it tends to depart still farther from it.

EXPERIMENT.

Apparatus.—Pendulum stand ; cord ; deal rod ; wooden blocks of various shapes ; card-board ; ball.

1. Find, according to the method described below, the Centre of Gravity of a uniform straight rod (the light wooden rod used in Exercise V.) ; a parallelogram ; a circular lamina ; a triangular lamina ; a kite-shaped lamina ; a sphere ; a cube ; a pyramid ; a cone ; and any irregular body. For the parallelogram, circle, triangle, kite, card-board may be used. Cut the pieces out of card-board and suspend each in turn on a pin stuck through at the desired

points. Take the parallelogram, for instance, stick a pin through, near one corner, in such a way that the card swings freely. When it has come to rest, take a cord with some heavy body at the end, hold the cord against the pin, and when the bob has come to rest, draw lightly, with a pencil, along the string on the face of the card. Then remove the pin, suspend from some other corner (not the opposite one) in the same way, and repeat the operation. The intersection of these lines will be the Centre of Gravity. Try a third position also, and note that the intersection is at the same point.

Draw the outline of the figure carefully in your notebook, showing the lines determined by experiment, and showing also how the Centre of Gravity could be determined by geometrical construction.

Repeat this manipulation with the other bodies, and record in a similar manner.

The position of the Centre of Gravity of the irregular body may have to be estimated. If so, estimate as closely as you can, and show clearly in your notes the experimental data.

If the experimental determination is carefully made, it will be found that the Centre of Gravity of a triangular lamina is at the intersection of the medians (the median is the line joining any angle with the centre of the opposite side). In the pyramid or cone it is on the line joining the apex and the Centre of Gravity of the base, three-fourths of its distance from the apex.

2. Using any suitable bodies you have at hand, note the difference between stable, unstable, and neutral equilibrium. Give full, but not long descriptions in your notes, showing what bodies are used, the conditions, your observations and conclusions. The pendulum, an iron or glass ball, blocks of wood, and small square boards may properly be used for this experiment. Try the blocks on a base, on intersection of two sides and on intersection of three sides ; the boards on edge and flat.

EXERCISE VII.

LEVERS AND PULLEYS.

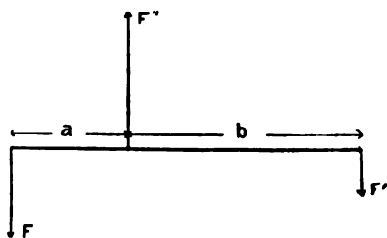
In Exercise V. we considered parallel forces; we saw what is the moment of a force; and in the experiments we used an apparatus which is essentially a *lever*.

A *lever* in its simplest form is a rigid bar which has one point fixed so that the lever turns about it. This fixed point is called the *fulcrum*. The *arms* of the lever are the perpendicular distances from the fulcrum to the lines of action of the forces.

In taking up problems on the lever there is but one principle which we need to bear particularly in mind, and that is the principle of the equality of moments in the case of equilibrium. The moment of each force must, of course, be found with regard to the fulcrum. It is usual to divide levers into three classes, according to the situation of the fulcrum with regard to the forces. This classification, however, is a merely arbitrary arrangement, which is seldóm of assistance to the student. Every case, whatever it may be, is most easily solved by the direct application of the principle of moments. This principle is perfectly general, and is applied in the same way, whatever the relative positions of fulcrum and forces.

Let us consider the case of the straight rod, in Exercise V., suspended at some point between the two forces which act at its ends. If the system be in equilibrium we shall see that it may be looked upon as belonging to any one of the three classes of levers, and that the solution is essentially the same in each case. As the system is in equilib-

rium, it does not move, of course. However we regard



it then, the force F'' must be equal to the sum of the two forces acting against it.

Now, let us assume the point of application of F'' to be the fulcrum. Then, for equilibrium the moment Fa must be equal to the moment $F'b$.

$$Fa = F'b \quad F'' = F + F'$$

$$\frac{F}{F'} = \frac{b}{a} \text{ or } F : F' :: b : a$$

We have thus determined the relative values of the forces F , F' , and F'' , so that if any two of them and the distances a and b are known, the other force may be found. This is usually called the first class of levers.

Suppose the point of application of F' be considered the fulcrum. Then the sum of the moments of the other two forces about that point must be zero. As these forces act in opposite directions, the moments are of opposite sign, and they may be equated as before. That is,

$$F(a + b) = F''b$$

and, as before, $F'' = F + F'$

$$F(a + b) = (F + F')b$$

$$Fa + Fb = Fb + F'b$$

$$Fa = F'b$$

and

$$\frac{F}{F'} = \frac{b}{a}, \text{ as before.}$$

If, now, the point of application of F be considered the fulcrum, the solution is similar. Equating the moments of F'' and F' about that point,

$$F''a = F'(a + b)$$

$$F'' = F + F'$$

$$\therefore (F + F')a = F'(a + b)$$

$$Fa + F'a = F'a + F'b$$

and

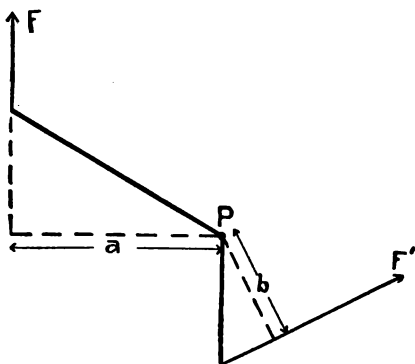
$$Fa = F'b, \text{ giving}$$

$$\frac{F}{F'} = \frac{b}{a}, \text{ as in the other two cases.}$$

These last two cases do not show the usual division into classes. Evidently, then, the division into classes is merely a distinction without a difference, and all cases may be solved in the same way, any of the points being chosen as a fulcrum. It must always be recognized that every case of the use of a lever involves a balance of a system of parallel forces, if the lever is straight. If the lever is not straight, the only forces to be considered are those which are perpendicular to its arms. These may be treated precisely as though they were parallel and the lever straight.

Let us take a perfectly general case. We have a rod bent at an angle—called a “bell-crank lever”—and the

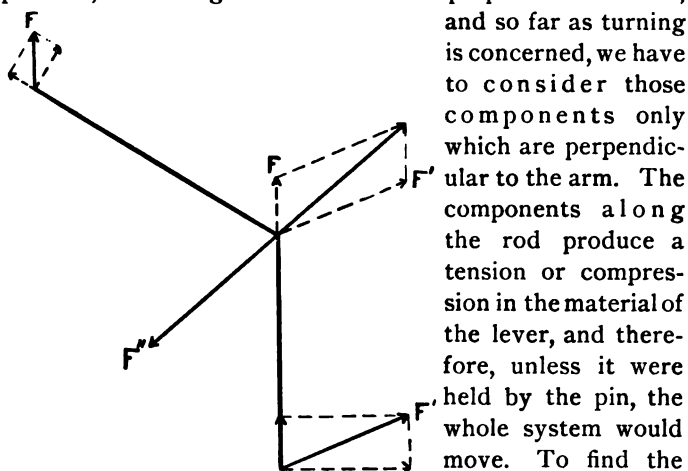
forces acting upon it are not perpendicular to its arms. To find the relations between F and F' , draw a perpendicular from the point P upon the line of action of each force. Then, if these perpendicular distances—the “arms” of the lever—are a



and b respectively, the moments are Fa and $F'b$. These are all we need so far as the relations between F and F' are concerned, and evidently we can just as well consider the lever to be straight and its length $a+b$. We cannot, however, in this way, find the actual pressure upon the pin, either in direction or magnitude. For this purpose a slightly different treatment must be used. The results for F and F' will be exactly the same whichever method be used; for whether it is the force or the arm which is re-

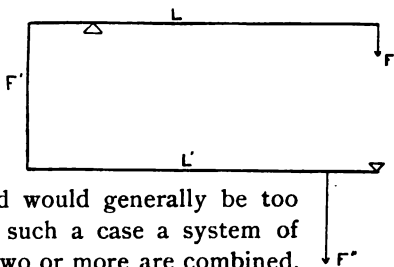
solved, the product of the perpendicular components will be the same.

The forces F and F' may each be resolved into two components, one along the rod and one perpendicular to it;



and so far as turning is concerned, we have to consider those components only which are perpendicular to the arm. The components along the rod produce a tension or compression in the material of the lever, and therefore, unless it were held by the pin, the whole system would move. To find the force exerted by the pin, the forces F and F' must be applied to it, and their resultant found. The reaction of the pin is then F'' , equal and opposite to the resultant of F and F' . This, however, is really a separate problem. We are usually concerned, in the case of any lever, only with the tendency of the forces to turn it; and for this purpose we have to consider only the components perpendicular to the rods.

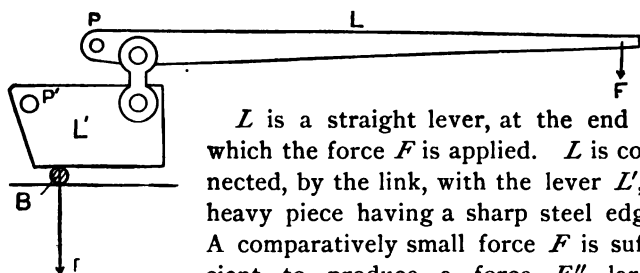
When it is desired to obtain a considerable multiplication by the use of a lever, a single rod would generally be too long and unwieldy. In such a case a system of levers is used in which two or more are combined. Suppose the two rods to be connected at the ends F' by a cord. Then, when the force F is applied, the value of the



force F' can be found in the usual way. That is all there is to be done for the lever L . We now take up L' , and from the force F' and the dimensions we find, by means of the moments, the force F'' .

The ratio F'/F , or the ratio of the second force to the first, is called the "Mechanical advantage," or the "Multiplying power" of the lever. In the case of any system of levers the multiplying power of the whole system is the product of the multiplying powers of the separate levers.

One of the most common applications of a system of straight levers is the shears for cutting iron rods or bars. The machine is, in principle, as shown in the diagram.



L is a straight lever, at the end of which the force F is applied. L is connected, by the link, with the lever L' , a heavy piece having a sharp steel edge. A comparatively small force F is sufficient to produce a force F'' large enough to cut a pretty heavy bar B . P is the fulcrum about which L turns, and P' the fulcrum of L' .

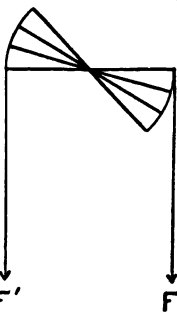
Some familiar examples of simple levers are, a balance ; a crowbar ; a claw hammer ; an oar ; the human arm and the foot ; a pair of shears ; nut crackers.

For complete solution of any problems in levers, the weight of the lever itself must be taken into account. The course to be pursued is sufficiently indicated in the matter on parallel forces.

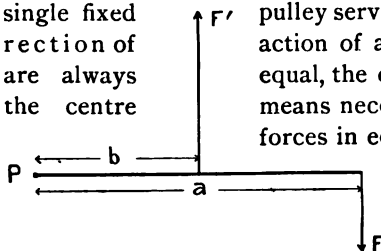
PULLEYS.

If we have a straight lever of equal arms and allow the forces to act so that the lever moves, the effective length of the arm will diminish as the lever ceases to be at right

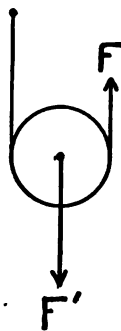
angles with the forces. Suppose, however, that when the lever has just passed this point another lever is inserted, perpendicular to the forces, so that the length of arm shall remain as before. If this process be continued as the lever continues to move, the result will be somewhat as indicated in the figure, and the point of application of each force will continue at the same distance from the fulcrum. The curves formed by the outer ends of the levers will then be arcs of a circle; and if the operation be continued, a F'



circular block will result, turning about its centre, and having the point of application of each force at some point on its circumference. Such an apparatus is called a *pulley*. Evidently, then, a pulley may be considered a lever of equal arms. A single fixed pulley serves merely to change the direction of a force. For, as the arms equal, the equality of moments about means necessarily the equality of the forces in equilibrium.

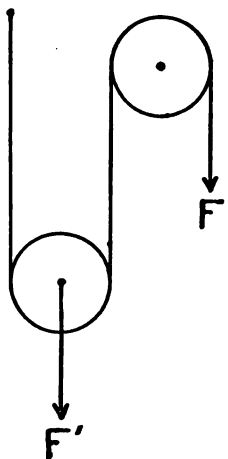


Pulleys are, however, combined into systems so that a smaller



force may be made to balance a greater one. The principle is, of course, the same as in the combination of levers. If a lever be arranged as shown, the arm a being twice as great as b , and the point P being the fulcrum, the force F' will be twice as great as F . If then, we take a pulley, with one end of the cord fixed, and the force F' exerted from the pin, or shaft, the multiplying power is 2; for, in this case, the point of the rim where the stationary cord touches is always the fulcrum, and the case is just the same as that of the single lever shown above.

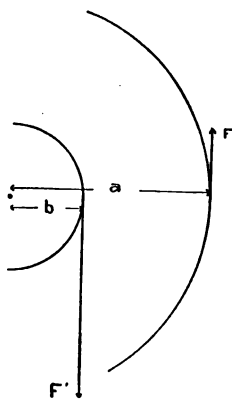
We may wish to change the direction of the force F . For this purpose a fixed pulley is used. If we add another movable pulley, in the same block with the first movable pulley, we again multiply by 2. This gives the common "tackle," so much used for raising weights.



This may be combined in other systems, and by suitable arrangements almost any desired multiplying power may be obtained. These are best investigated experimentally.

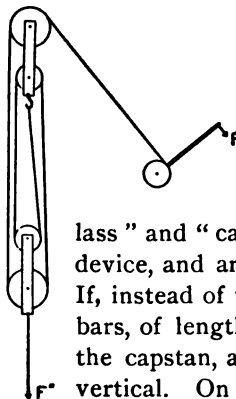
If we have two pulleys, of different diameters, rigidly fastened together, side by side, the result is the same as in the case of the lever shown, where a is the *radius* of the larger pulley, and b the radius of the smaller. This arrangement forms a machine commonly known as

the "wheel and axle." Its multiplying power, or mechanical advantage, may be



worked out in the manner already described. The "wind-

lass" and "capstan" are modifications of this same device, and are probably familiar to most students. If, instead of the larger wheel, a crank or a series of bars, of length a , be used, we have the windlass or the capstan, according as the axis is horizontal or vertical. On a common derrick the mechanical advantage is obtained by a "double block and fall," or "tackle," as described above, and a windlass. The power is



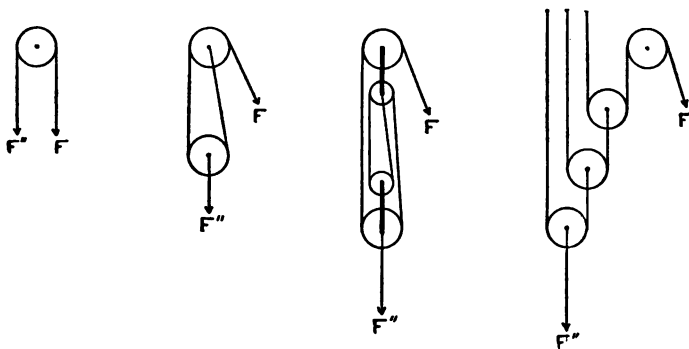
applied at the crank of the windlass, and the rope, winding around the drum, of smaller radius than the crank, transmits the increased force through the pulleys. The weight is raised, or the force F'' applied at the shaft of the movable pulleys.

All of these cases may be very simply worked out by the principle of moments. It will usually be necessary to take account of the weight of the moving parts. This may be done by calculation after weighing, or a small counterweight may be applied to the cord.

EXPERIMENT.

Apparatus.—App. A : cord ; brass weights ; four pulleys.

Place Apparatus A with the end carrying the pulleys projecting over the edge of the table. Then, with weights, making proper allowance or correction for the weight of moving parts, find the multiplying power of the pulleys and systems of pulleys shown below. The upper pulleys are supposed to be fixed.



Sketch in your note-book the system of pulleys in each case, and place beside the proper points the amounts of the weights F and F'' . Determine also, by computation, or in any other way you can, the force exerted by each cord.

Note the value of the force beside the line representing the cord.

Determine also, by experiment, the relation between the distances moved through by the weights in each case. That is, let the point F move through, say, ten centimetres, and measure carefully the distance through which the point F'' moves in the same time.

Note this ratio below each diagram. What general conclusions do you draw from these results? How does the ratio of distances compare with the ratio of corrected weights?

In a derrick equipped with windlass and double blocks, previously described, the diameter of the windlass drum is 6 inches; the length of crank, from the centre of the shaft, is 15 inches; and the force exerted on the crank is 50 pounds. What weight will be raised by the movable pulleys, neglecting weight of pulleys and friction?

EXERCISE VIII.

BREAKING STRENGTH OF A WIRE.

EXPERIMENT.

Apparatus.—App. A.; dynamometer; brass and steel wire; wire gauge; soft copper wire and hard-drawn copper wire.

Two students may work together in this experiment.

Before beginning the experiment, cut off three specimens, each 1 metre long, from each wire. Weigh one specimen of each material, and record the weight. Find the average diameter of the wire by means of the wire gauge. Then proceed with the test according to the instructions. Particular care must be taken that there are no kinks in the wire, and that it does not bear against any sharp corners.

Each specimen of wire is to be fastened as follows: Attach the dynamometer in such a manner that it hangs properly and is clear of the supports. Attach one end of the sample to the free end of the dynamometer, taking care that in making the joint the straight portion of the wire is not bent or twisted in any way. Pass the other end of the specimen through the hole in the pin at the other end of the board.

Then turn the pin, by means of the wrench, until the wire is just straightened out. Note the reading of the dynamometer. Make two marks on the wire, as accurately as possible, 50 cm. apart, marking in such a way as not to injure the surface of the wire. Turn the pin again until the dynamometer reads twice as much as before. Measure

carefully the distance between the marked points. Increase the tension on the wire, by turning the pin gradually, occasionally noting the dynamometer reading and the distance between marks. As the tension increases, the dynamometer must be closely watched, and its reading at the point of breaking carefully noted. As the broken ends of the wire may fly, take such a position that you will not be struck by them.

Record your observations in a table as follows, filling in the calculated values afterward. These values should be found once for each material, from the averages for that material. Soft copper and hard-drawn copper cannot, of course, be considered as the same material.

No. of Specimen.	Material.	Diam.	Wt. 1 Metre, in Grammes.	Dynamom. Readings.	Dist. betw. Marks.	Max. Load.	Max. Load p. Sq. In.

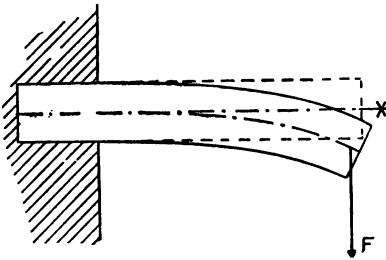
Three extra samples each of hard-drawn and of soft copper should then be taken, and a slight nick made in the surface with a sharp file. Break them then, as the other samples. No length measurements need be made on these pieces. Compare the results with those for the sound specimens of the same wires, and state the conclusions you draw from the comparison.

EXERCISE IX.

DEFLECTION OF BEAMS.

When a beam or rod of any material, fixed or supported in some way, is loaded, if the load is not greater than it will bear, the beam will bend. This bending may be so small as to be inappreciable except by most careful measurement, but some bending always takes place. Evidently, the amount of deflection will depend on the load, the material of which the beam is made, its size and shape, the nature of the support, and the distance from the point of support to the point of application of the load.

Let us suppose that we have a beam of wood, rectangular in cross-section, one end firmly fixed into a wall, and the other end loaded. A beam so supported and loaded is called a "Cantilever." Evidently, the beam will bend in



the way shown in the figure, and the vertical distance through which any given point moves is called the *deflection* of the beam at that point.

A consideration of the action here will make it evident that the upper portion of the beam will be under a tension; that is, the fibres in the upper part will be pulled out, or extended. The lower fibres will, on the contrary, be pushed together, or compressed, in the direction of their length. As the forces in the top and those in the bottom act in

opposite directions, there must be some line along the length of the beam in which there is no resultant force. This line is called the *neutral axis*; and of course the tension above it just balances the compression below it. Let us suppose the beam to be so uniform in structure that this axis is just along the middle. Then the forces of reaction, due to the elasticity of the material, will balance the forces due to the load. That is, there will be an outward push along the lower fibres, and a pull along the upper fibres, forming a *couple** which tends to straighten the beam out again. In calculating the total force exerted by the material of the beam, we should have to take into account each layer of fibres, in pairs, one above and one below the neutral axis, and at the same distance from it. Then the effect of all these elemental couples must be added together. Evidently, then, without going deeply into this calculation, the force exerted by the beam will increase as the depth of the beam is made greater, and will increase more rapidly than the first power of the depth, since its strength is in proportion to the sum of the moments of the couples. That is, if the beam is made twice as deep, its strength will be more than twice as great.

The width of the beam, however, affects its strength only as its first power; that is, a layer of fibres of double the width will be only twice as strong. One object in experimenting on this subject is to verify our reasoning as to the effect of change in width, and to find out to what extent the strength is affected by change in depth.

Other points, however, which are evident on a simple consideration of the problem, are, first, that the greatest strain in the beam is not where the weight is applied, but

* A *couple* consists of a pair of equal forces acting in opposite directions at the ends of a lever, thus tending to turn the lever about its centre. As both forces tend to turn it in the same direction, their moments must be added.

nearer the support ; and second, that as the fibres near the neutral axis are of less effect than those far from it, we may advantageously take some away from that portion and place them on or near the upper and lower edges. For a given weight, or amount of material, such a beam as the I beam, which is so much used in all kinds of construction, and which is probably familiar to most students, is considerably stronger than a beam of rectangular cross-section ; and we should expect, also, that a beam deeper than it is wide would be stronger than one wider than it is deep.

If the loads used are not so great as to produce a permanent change of shape, the strength of a beam may be simply measured by means of its deflection. For our purposes, moreover, we need to know only the relative stiffness of different beams.

EXPERIMENT.

Cantilevers.

Apparatus.—App. A ; weights ; metre stick ; wooden rods of even grain, each 80 centimetres long, and of cross-section as follows :

Rod No. 1, 4×16 mm.

“ “ 2, 8×16 “

“ “ 3, 8×8 “

Two students should work together on this experiment.

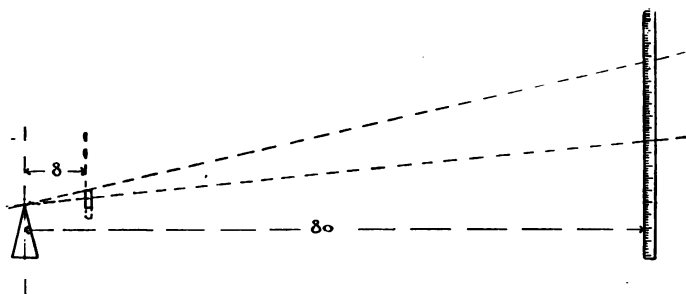
Rods No. 1 and No. 3 are of the same cross-section. Rod No. 2 is of twice this section, being twice as wide as rod No. 1, and twice as deep as rod No. 2. Rods No. 1 and No. 2 may each be used in two positions, on edge and flat, and each may be regarded as a different beam in each position. Measure the cross-section in each case.

Find the deflection of each rod, in each position, as follows :

Fasten the rod to be tested in the clamp, leaving, between the edge of the clamp and the point of application of the load, a free length equal to a little less than half the length

of the rod, or about 40 centimetres. Read the position of the beam in the manner described below. Hang upon the free end a weight of 50 grammes. Note the deflection. Remove the weight and read the position of the rod again. This zero position should be read both before and after each deflection, and when any permanent bending is found, no greater weight should be added.

The deflection will usually be difficult to read if the observation is made from the beam directly. A ready method of determining the deflection is as follows: Place beside the rod, and about 8 cm. from it, one of the bridges of App. A, so that the edge of the bridge comes slightly below the top of the rod. On the other side of the rod and about 80 cm. from the bridge, place a metre stick vertically. Standing on the farther side of the metre stick, sight across the rod and the edge of the bridge from such a point that the



top of the bridge is in line with the upper edge of the rod, at the point where the weight is hung. The edge of the rod will then appear to cut the scale at a point which may be read off. This reading may be facilitated by the use of a card sliding on the scale, the upper edge of the card being brought into line with the upper edges of the rod and the bridge. If the distances of the rod and the metre stick from the bridge are as given, 8 cm. and 80 cm., then the actual deflection of the beam will be to the difference in readings as 8 to 80; that is, the movement of the beam is

multiplied ten times. Any other relation may be used, but in any case the distances must be noted with some care.

Having found the deflection with a load of 50 grammes, repeat with a load of 100 grammes, if not too great; then with a load of 200 grammes.

It will be found convenient to test the rods in the following order :

1. Rod No. 1, flat.
2. " " 2, flat.
3. " " 3
4. " " 2, on edge.
5. " " 1, on edge.

The three rods in their different positions will then be equivalent to five distinct beams.

Bind together, with cord, two of rod No. 1, making a compound beam of the same size and shape as No. 2, and test flat, in the same way. Compare the results with those for No. 2.

To determine the influence of length, select the rod most convenient for the purpose and go through the same process as before, making its free length half that used in the first case.

Record your results in a table as follows :

Cross-Section and Position of Beam.	Length.	Load.	Reading, with Load.	Reading, no Load.	Mean Zero.	Difference in Scale Reading.	Deflection of Beam.
 Mm. 4 x 16	Cm. 40	Gm. 100	Cm. 60.10	Cm. 64.20 64.18	Cm. 64.19	Cm. 4.09	Cm. 0.41.

An assumed case is given in the table, to show how the entries should be made. Placing the diagram of the cross-section in the vertical position, in the first column, shows that the beam was tested on edge. For the beam in the

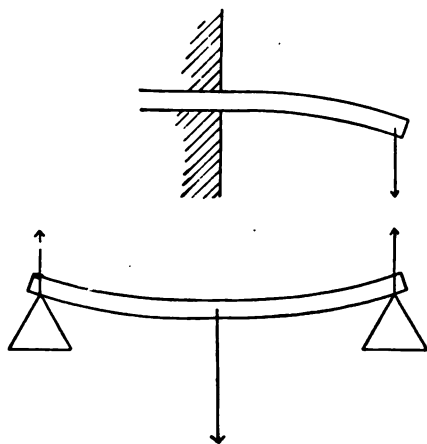
flat position, the diagram of cross-section should be drawn horizontally. Enter all results in the same table.

Having completed all the tests, examine the results carefully, and see if you can determine, from them, the way in which the strength of a beam is affected by each of its dimensions. State your conclusions and your reasons for them, giving all necessary steps.

EXERCISE X.

DEFLECTION OF BEAMS.—(*Continued.*)

Suppose now, that instead of a beam firmly fixed at one end and loaded at the other, we have one simply laid across



two supports and loaded at the middle. Evidently this beam will bend down in the middle, and there will be an upward force at each end, due to the reaction of the supports. We should have just these conditions if we took two of the first kind, joined the fixed ends together, and turned them over, so that the loads

acted upward. The downward force at the middle would then be twice the upward force at each end, and the length of the second beam twice that of the cantilever.

EXPERIMENT.

Beams Supported at Both Ends.

Apparatus.—The same as in Exercise IX.

Use the rods in all the positions tried in the last exercise. Instead of clamping them at one end, however, lay them

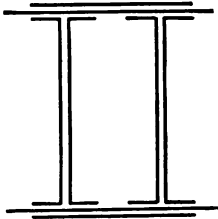
across the end bridges of Apparatus A. Make the distance between supports twice the free length of the cantilevers in Exercise IX. Apply the loads at the middle. The manipulation is in every respect the same as in the last experiment, and the results should be entered in a similar table. From the considerations advanced in the matter just before these instructions, determine what loads should be applied in each case, in order that a comparison may be made with the results in the case of the same rods used as cantilevers.

Compare the results of these tests with those in the last experiment and see if the reasoning given is borne out by this experiment.

EXERCISE XI.

TRUSSES.

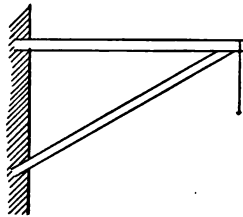
When great strength is required in a beam, to make it of a single piece would involve using a beam of enormous weight. As there are, in every beam, parts which bear but a very small load, these parts may be advantageously cut out, and the material put elsewhere. An example of economical distribution of material was given when the I beam was mentioned. I beams of iron or steel, when not too large, are rolled out in single pieces ; but when the beam is



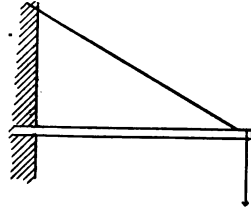
too large to be properly rolled out in one piece it is built up of sheets of steel riveted together. The cross-section of a large beam of this kind is much like that shown in the drawing, where each line represents a separate plate. There may be one or more *webs* added—the “web” is the thin vertical piece con-

necting the top and the bottom. Such a structure is still called a *beam*, however, or more usually a *girder*. If we make a combination of several beams or rods, we produce what is known as a *truss*.

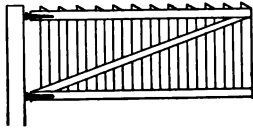
The origin and development of the simplest forms of truss are very evident. Suppose we have a simple cantilever, and find it not strong enough, and that using a single beam of sufficient strength is impracticable. There



are two courses which suggest themselves. The first is to add a diagonal piece running from the end of the beam to the wall. This piece takes up most of the thrust, and prevents the cantilever truss, thus formed, from bending too much.

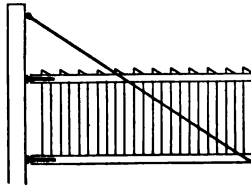


The second method is to add a rope or rod, from the end of the simple beam, upward to the wall. This acts to prevent undue bend-



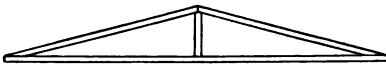
ing by exerting a tension which holds up most of the load. Simple and familiar examples of both these methods are the large gates seen on most farm lands. The gate is built in one of the two ways shown

in the diagrams; otherwise its own weight would cause it to sag so that it would not shut and might even fall to pieces.



In the first case the weight is borne by the diagonal and the upper horizontal pieces; in the second case, by the diagonal and the lower horizontal pieces.

When we consider the beam resting on two supports and loaded between them, we may apply these same simple ideas, remembering that such a beam is equivalent to a pair of cantilevers reversed and inverted. Thus, the first

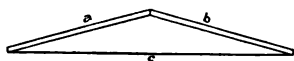


method of making a cantilever truss would give us a truss of this form,

the load being applied at the apex. This is, in fact, the simplest form of truss used for supporting roofs, the short vertical piece in the centre being often omitted.

A consideration of the conditions when such a truss is

loaded will show us that the two diagonal pieces are pressed together by the action of the load, and the horizontal piece is pulled. The different parts of

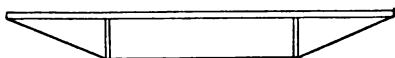


a truss are called "members"; a and b are therefore compression members, and c is under tension. c may be a cord or rod as well as a beam; for in tension the shape of cross-section makes no difference so far as strength is concerned.

The second method of trussing would give us a structure such as is shown in the next diagram. The horizontal beam, in this case, bends somewhat under the load, but is supported at the middle point by



the short vertical piece under compression—a "strut" as it is called—and the tension in the diagonal rods. The diagonals may properly be one piece simply passing under the end of the strut, which serves to hold them away from the beam. This principle is applied in the construction of floors of railway cars, and in a more complex form in the construction of bridges. These two methods, in fact, with the principle of the arch, are the foundation of all truss



construction, and may be seen, in more or less complex form, in all

structures which have to carry great loads.

Students are advised to study, so far as they can by inspection, any such work that they see: for example, the arches in any great railway train shed, the construction of iron bridges and of roofs of large buildings, such as mills or churches. It will not always be clear what members of a truss have to bear tension and what compression. Details of such complex cases may well be left for more advanced study; but it will be useful to notice, so far as possible, how the simple principles already explained are applied in practice.

EXPERIMENT.

Apparatus. App. A.; weights; steel or spring brass wire; fine wire or cord; device for measuring deflection; 1 wooden rod about 5 cm. long; 2 wooden rods about 20 cm. long; one of the rods used in Exercise IX.

Two students may work together on this experiment.

The long wooden rod may be used for the beam. Place it in the position of least strength, so as to obtain a considerable deflection. Give it a clear length of about 25 cm. Test it as a cantilever, as in Exercise IX., using but one weight, and find the deflection. Then place the shorter rod diagonally, under the beam, braced against the foot of the end block. It may be held in place against the beam by abutting it against a small brad or tack.

Apply the same load as before, and note the deflection. Care must be taken that the short rod is tightly in contact at both ends, without play. Then see if you can apply such a load as will give a deflection equal to that obtained with the simple beam. If the truss gives away, note where the failure occurs.

Having completed this test, remove the short rod, lash it tightly against the end block, behind the clamp, in a vertical position, and connect the point of application of the load, by a fine wire, with the vertical rod about 10 cm. above the beam. Make a similar test on this truss, and if much deflection occurs, note which member bends the most.

Then lay the beam across the bridges, 40 cm. apart, load the middle suitably and find the deflection, as in Exercise X. Construct, on this beam, the first form of truss, holding the members together by small brads and cord or wire. Take care that the truss does not topple over while under test. Apply to this the same weight previously applied to the beam, hanging it from the apex. Note the deflection,

if possible. Then see if you can so load it as to give a deflection equal to that obtained with the simple beam. Note where failure occurs.

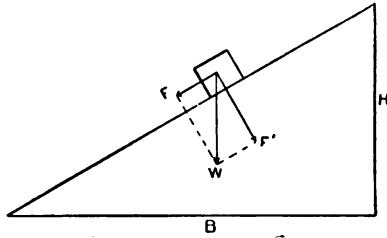
Construct the second form of truss, with fine wire and the shortest rod, passing the wire under the end of the rod and making it fast to the beam near the points of support. Repeat the former test.

All observations and results should be entered in a table, as in Exercises IX. and X.

EXERCISE XII.

THE INCLINED PLANE ; FRICTION ; WORK AND ENERGY.

When a heavy body moves on a plane surface which is not level, we all know that it tends to slide or roll down the plane under the action of gravity. The force due to its weight acts downward. This may be resolved into two forces at right angles, one acting along the surface and the other perpendicular to it.

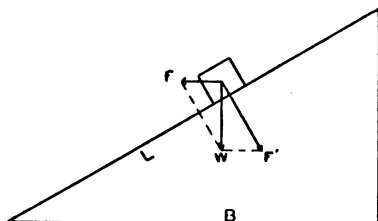


We can thus determine the force with which a given weight is urged down a plane inclined at a known angle to the horizontal, and the force with which it presses against the surface. If W is the weight of the body, it is urged down the plane by a force F ; and is pressed against the surface with a force F' . An inspection of the figure will show that

these two component forces are related to each other as the height and base of the inclined plane are related. For the triangles so formed are similar, as their sides are equally inclined. Therefore $\frac{F}{F'} = \frac{H}{B}$; or $\frac{F}{W} = \frac{H}{L}$. Of course, the weight W may be resolved in any other way that is desired.

We have considered only the two components tending to produce motion down the plane and pressure against the surface; and assuming the surface to be perfectly smooth, the pressure must be perpendicular to it.

Suppose, however, that we have a piece cut out of a solid block of wood, for example, and that the body is held in



equilibrium against this block by a horizontal force. To find the forces acting in this case, we must resolve the weight differently.

The horizontal force which must be exerted, in order to balance the downward effect of the weight, is now F and the relation is $\frac{F}{F'} = \frac{H}{L}$, or $\frac{F}{W} = \frac{H}{B}$.

FRICTION.

We have assumed, so far, that the surfaces in contact were perfectly smooth, so that the pressure would be perpendicular to them. In practice, no surface, however carefully it may be finished, can be made perfectly smooth. If our microscopes were sufficiently powerful we should be able to see all the little inequalities. Now, if two surfaces are in contact, both being somewhat rough, and if one is made to move over the other, one of two things must happen. Either the projecting portions of one surface must rise over the raised portions of the other, or they must grind each other off. This grinding action of surfaces which are pretty nearly smooth is used in making "surface plates," so called, and is about the best method known for accomplishing that purpose. If the inequalities—the little hills and hollows—move over each other, as a hill on one passes over a hill on the other, the two bodies must be sep-

arated slightly. This necessitates the exertion of a force acting against the weight. The phenomenon known as *friction* is due to both these actions.

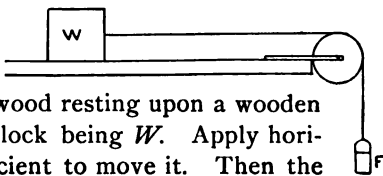
If two surfaces are allowed to remain in contact and at rest for some time they will usually become so adjusted to each other that some of the little projections on one fit into the hollows on the other. A considerable amount of force may be necessary to start them out of this adjustment; but when once in motion past each other, there is not time in any one position for such adjustment to take place, and a less force will keep them in motion than was required to start them from the position of rest. That is, the *friction of repose* is usually greater than the *friction of motion*.

Experiment has shown that the force necessary to overcome friction due to the weight of a given body is dependent solely upon the weight and the nature of the surfaces in contact, and not at all upon the area of the contact surfaces; provided, of course, that one surface is sufficiently great not to cut into the other and form a depression that it must be lifted out of. It is found, also, that within reasonable limits the friction of motion is independent of the velocity with which the surfaces move past each other.

As the force necessary to overcome friction is independent of area of surface, and is, for two given surfaces, simply a certain fraction, or per cent. of the pressure between them, it is possible to find, for every two surfaces in contact, a number which expresses the ratio between the force exerted and the pressure between the surfaces—that is, the force, let us say, in pounds' weight, for every pound's weight of pressure. This is called the *coefficient of friction*.

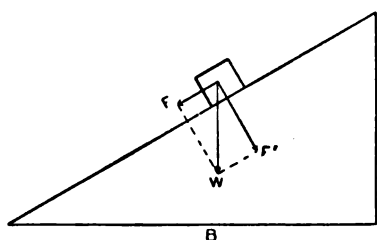
There are two ways of determining the coefficient of friction. Suppose

we have a block of wood resting upon a wooden table, the weight of the block being W . Apply horizontally a force just sufficient to move it. Then the



ratio of the force to the weight, or $\frac{F}{W}$ is the coefficient of friction for those particular surfaces.

Suppose now we rest the block upon a plane surface whose inclination can be varied. Increase the pitch until the block just moves.



Then the force F , urging the block down the plane, and the force F' , causing pressure between the surfaces, are proportional to the weight, W , and for the

same contact surfaces the inclination will be the same when the block begins to move, whatever the weight. The coefficient of friction is, in this case, $\frac{F}{F'} = \frac{H}{B}$.

It is determined, therefore, by making the pitch such that the block just moves, and finding the ratio $H : B$.

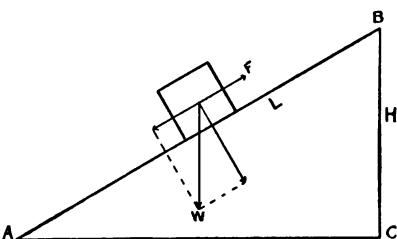
WORK AND ENERGY.

We have thus far dealt only with forces. When a force acts through a distance, it is said to do *work*. Work, therefore, always involves the overcoming of a resistance through a distance, and the work done is measured by the product of the force exerted by the distance through which its point of application moves. However long we may exert a force, or however great a force may be, we do no work unless the point of application of the force moves. If I raise a weight from the ground I do work upon it; but although I may hold it in its raised position for an indefinite time, I am only exerting a force, not doing work. The power to do work is called *energy*.

Suppose a weight is pulled up a perfectly smooth inclined

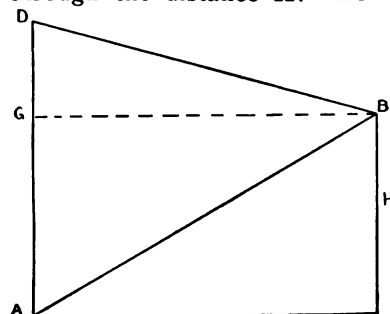
plane, by a force parallel to the plane, from A to B . The work done is measured by the product $F \times AB = FL$. But $\frac{F}{W} = \frac{H}{L} \therefore FL = WH$

Therefore the work done by the force F , in moving the weight from A to B along the plane, is exactly the same, neglecting any friction, as



that done in raising the weight vertically from C to B , or through the distance H . We might prove that the work

done on the body is the same from A to B , by any path whatever; for, although the work done in raising the weight to D is $W \times AD$, the *body does work* in falling from D to B . This work is therefore negative and must be subtracted.



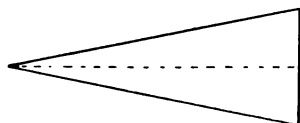
The work done on the body is therefore :

$$W \times AD - W \times DG = W \times AG = WH$$

So far as work is concerned, there can be nothing gained by the use of any form of machine. For the distance through which the force moves increases in the same proportion that the force diminishes, so that the product of force by distance is the same. This principle should be applied to the case of the levers and pulleys. We shall find that the product of the force by the distance is the same for any given system of pulleys or of levers. That is, referring to the exercise on pulleys, the product of the force F by the distance through which it falls is equal to the product of the force F'' by the distance through which it is raised.

The inclined plane is another form of machine, and is

called a *wedge*. As the wedge is driven through its length, it overcomes the resistance through its height. A me-



chanical advantage is secured, as the driving force is less than the resistance ; but the work done in driving the wedge is the same that would be exerted in

overcoming the resistance directly through the distance over which it moves.

If an inclined plane is wound about a cylinder, another form of machine is produced. This is the *screw*. The same principles as to work done apply in this case.

In any actual machine, friction is unavoidable. The work done by the power must, therefore, be enough greater than that done upon the weight to overcome the frictional resistance also ; and we must take into account, as well, the work done against the weight of the moving parts of the machine, which produces no useful effect.

Although the total amount of work done in any case is independent of the time, being measured only by the product of force by distance, the time occupied in doing any given work usually has to be taken into account. The amount of work done in a unit of time is called the *rate* of work. The unit of *rate of work* generally employed is the "horse-power." This is an arbitrary unit, one horse-power being equivalent to raising one pound through 33,000 feet in one minute, or 33,000 pounds through one foot in one minute or any other combination which produces 33,000 foot-pounds in one minute.

EXPERIMENT.

Coefficient of Friction and Inclined Plane.

Apparatus.—App. A ; weights ; metre stick ; block of wood ; glass plate.

Two students should work together on this experiment.

1. *Coefficient of Friction.*—Place the block upon the board, and change the inclination of the board until the block just moves. Do not start the block by jarring the board or the table. Measure carefully the base and the height of the triangle of which the board and the table form two sides.

The ratio $\frac{H}{B}$ is the coefficient of friction. It is convenient,

in finding $\frac{H}{B}$, to measure, from the corner of the board in contact with the table, some even distance for a base, say 50 cm. or 100 cm. From that point measure vertically upward to the under side of the board. Make not less than five trials for each pair of surfaces, and take the average value.

Try in this way wood on wood, with the grain of both pieces running the same way and with the grain crossed; glass on wood; and any other surfaces you may have at hand.

Record the observations in the following form :

Surfaces.	B.	H.	$\frac{H}{B}$	Mean.

2. *Inclined Plane.*—Weigh the wooden block. Support the board of Apparatus A in an inclined position. Fasten a cord about the middle of the block, pass it over a pulley clamped at the upper end of the board, and attach a weight at the other end of the cord. Then lower the inclined plane, moving the support, until the block begins to move up the plane. Since the block moves, the weight applied must be somewhat more than sufficient to counterbalance the component of the weight acting down the plane, the friction of the block and that of the pulley. The friction of the pulley may be neglected, as, in individual cases, the varia-

EXERCISE XIII.

COMPOSITION OF MOTIONS ; VELOCITY ; ACCELERATION.

Any body or particle, when displaced from one position to another, must pass through a series of successive intervening positions. It thus describes a line or curve which is called its *path*.

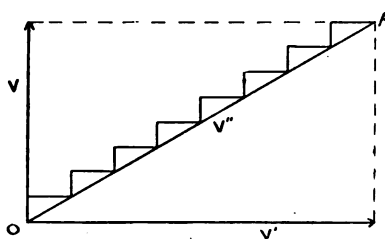
The *velocity* of a moving particle is the rate of change of its position. That is, if the motion is uniform, the velocity is the length of the path described in a unit of time. The velocity, however, is not fully described until its direction is given.

When the velocity of a particle is not constant, the velocity at any instant is the length of the path that would be described by the particle if it continued to move at the same rate for a unit of time. Thus we say that the velocity of a train at a given point is 50 miles an hour ; for, if the train continued to move for an hour at the speed with which it was moving when passing that point, it would describe a path 50 miles in length.

The velocity of a moving body is seldom constant, however, and the rate of change of the velocity is called the *acceleration*. That is, taking the second as the unit of time, the acceleration is the amount by which the velocity changes in one second. If the velocity is increasing, the acceleration is positive, and is therefore to be added to the velocity for each second ; but if the velocity is diminishing, the acceleration is negative and must be subtracted in the same way. Let us assume that a body starts from rest, with an acceleration of 32 feet a second. Then, as the velocity

at the start is nothing, adding the acceleration would give, at the end of the first second, a velocity of 32 feet per second; at the end of the second second, a velocity of $32 + 32 = 64$ feet per second; at the end of the third second, $64 + 32 = 96$ feet per second, and so on. We shall need to consider, in our work, only two cases, namely, that in which the velocity is uniform, and that in which the acceleration is uniform.

Motions, or velocities, may be compounded just as forces may be. Let us assume that we have two velocities impressed upon a particle simultaneously. For simplicity, let us suppose that the velocities are equal in magnitude, and at right angles to each other; and that they act alternately for very small intervals of time. The motion of the particle will be that shown in the diagram. As we make the



intervals smaller and smaller, the broken line OA will approach more and more nearly to the straight line OA ; so that, if the velocities V and V' act together, they will be equivalent to the

diagonal, V'' , of the parallelogram constructed on V and V' , as in the graphical composition of forces. The diagonal represents the direction in which the particle moves.

Let us take a more complicated case. Let one of the velocities be constant, and let the other change by a constant amount every second. That is, the particle has a constant velocity in one direction and a constant acceleration in a direction at right angles to the first. The position of the particle may be found graphically for every succeeding second, and the line drawn through the successive points so found will be the path of the particle. The line so drawn should not be a broken line, but a smooth curve passing through all the points; for the acceleration is acting with a

constant value all the time, and the particle will therefore make no sharp turns.

Construct in your note-book a curve showing the path, for six seconds, of a particle moving with a constant horizontal velocity, to the right, of ten feet a second, and a constant downward acceleration of four feet a second. Evidently, the origin should be chosen at the upper left-hand corner of the page, and the scale should be such as will make the curve take up as nearly as possible the whole page. Follow the instructions previously given for plotting curves.

MOTION UNDER THE ACTION OF GRAVITY.

When a heavy body falls to the earth, every one knows that it moves faster and faster as it falls. That is, it moves with an *acceleration*, and unless there are resistances which counterbalance the action of this force, the velocity will increase by a certain definite amount for every successive equal interval of time. If we remove these sources of resistance by causing the body to fall in a space from which the air is exhausted, we find that all bodies, of whatever size or kind or shape, fall with an acceleration which is always the same at the same point on the earth's surface, but which varies somewhat for different places. This acceleration of gravity is always denoted by the letter g . Its value for our latitude is about 32.2 feet per second, or about 980. centimetres per second.

Force has been already defined as that which tends to produce motion. We know, however, from our experience, that to produce a given velocity in a small mass, in a certain time, takes less force than to produce the same velocity in a large mass, in the same time. Force may, in fact, be measured by the acceleration produced in a given mass in a known time.

The *momentum*, or what may be called the "quantity of

motion," of a body, is the product of the mass by the velocity.

All the facts which have been stated in regard to moving bodies are stated in a very concise form in what are known as *Newton's Laws of Motion* :

1. Every body continues in its state of rest, or of uniform motion in a straight line, except in so far as it is compelled by external force to change that state.

2. The rate of change of momentum is proportional to the impressed force, and takes place in the direction in which the force acts.

3. To every action there is an equal and opposite reaction.

The first law embodies the principle of inertia, with examples of which every one is familiar. The destructiveness of cannon shot, and of a railway wreck ; the effect in the children's game of "Snapping the whip ;" the motion of a base-ball after leaving the hand ; and in fact almost every occurrence in our daily life are examples of action under this law.

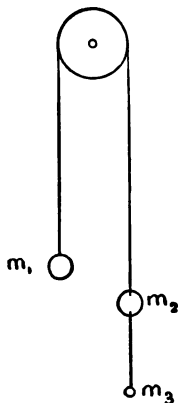
The second law gives us the only really accurate method of measuring force.

The third law may be taken to include the principle of the conservation of energy. That is, the total energy in any system of particles cannot be changed by any action within that system. The statement itself means literally only that every force is exerted equally in both directions. There is as much force exerted on the gun as there is on the bullet, and in an opposite direction. Every such mutual action forms a *stress*. The distortion produced by the stress is called a *strain*.

In the investigation of the motions of falling bodies by experiment directly, we are at once confronted by a considerable difficulty. The bodies fall so rapidly, and so great a vertical distance is required for any such experiment, that it is impossible to use any simple methods or

apparatus. We can see now why all bodies, whatever their mass, fall in the same time. The acceleration of gravity is the same for each unit of mass, and the acceleration of any body is therefore proportional to its mass. But the force necessary to produce a given velocity in a certain time is also proportional to the mass. Therefore the velocity acquired by every body in a unit of time, under the influence of gravity, must be the same.

Let us assume, now, that we have two equal masses connected by a string which passes over a pulley. Neglecting the weight of the string and the friction of the pulley, as the force on each is the same, the system as a whole will not move, but will remain in equilibrium. Now let us add to one side a small mass. There will then be an unbalanced force acting on the system, due to the attraction between the earth and the mass m_3 . If this mass, m_3 , were free, it would fall at such a rate that at the end of the first second its velocity would be 980 centimetres a second. But the acceleration on m_3 has to set in motion the whole system, $m_1 + m_2 + m_3$, so that the velocity acquired in one second will be much less than that of a freely falling body in the same time. We have thus a body falling according to the same laws as though it were free, but so slowly that its motion can be readily studied. Such an apparatus is called an Attwood's machine.



If the friction of the pulley is so great that it cannot be neglected, it may be necessary to place a considerable extra weight m_4 on one side, to make the system move. As the friction is constant, this will mean simply that the acceleration is less than we should otherwise expect; but the acceleration will still be uniform, and the relations between distance traversed and elapsed time will be preserved.

EXPERIMENT.

Falling Bodies.

Apparatus.—App. A ; weights ; metre stick.

Two students may work together on this experiment.

Place Apparatus A so that the pulley projects over the edge of the table. Take a cord equal in length to the distance between the pulley and the floor, and tie a small hook in each end. Hook an equal weight on each end, say 50 grammes. Add a smaller weight to one side, sufficient to make the system move slowly. Place the metre stick vertically close beside the falling weight, but not touching it. Care must be taken that the weights do not swing while falling. Hold the weights in position, read on the metre stick the position of the bottom of the falling weight. Release the weights just on the tick of the clock and allow the system to move. Place a block or piece of card-board in such a position that the falling weight strikes it just at the next tick of the clock. This can be done pretty accurately after a few trials. Read the position of the top of the block. The difference between the first and second readings gives the distance moved through by the system in one second. Make three trials and find the average. Then find, in the same way, the space traversed in two seconds, and in three seconds, if the distance is sufficiently great, making three sets of readings in each case.

Increase the moving mass to any suitable amount, say 100 grammes on each side, still adding the small weight to one side, and repeat. Record observations in the following form :

m_1 .	m_2 .	m_3 .	Upper Reading.	Lower Reading.	Diff.	Average.	Elapsed Time.

From these results determine the relation between the space traversed by a falling body in one second, that traversed in two seconds, and so on. Averages should be used for this determination ; but of course the results obtained with any one value for the moving mass cannot be averaged with those obtained for some other value.

EXERCISE XIV.

THE PENDULUM.

Any mass swinging freely from some point of support forms a pendulum. The *simple pendulum* consists, theoretically, of a heavy particle suspended by a cord of no weight. It is of course impossible to realize these conditions in practice, but we can come sufficiently near for our purpose by using a very light cord having a heavy spherical mass at the free end. The mass is called a *bob*. The "length" of a pendulum is not, as might be supposed, the distance from the top to the bottom, but is the distance from the point of support to the particle, in a simple pendulum which vibrates in the same time as the one in question. In the pendulum formed of a cord and heavy ball, the length may be taken as the distance from the point of support to the centre of the ball. This is not the true length; but the difference is very slight, if the ball is not large and the cord not too short.

When a ball, so suspended, is drawn aside from the vertical and then released, the action of gravity causes it to fall toward its position of rest. It acquires such momentum however, in falling, that it cannot stop there, but rises on the other side. If there were no friction of any kind, and no other resistance to its rising but the pull of gravity, we know from the laws of motion that it would swing as far to the left as it was pulled to the right; and that it would then return, repeating these vibrations forever.

It is found that the time in which a pendulum makes a vibration is shorter as the length of the pendulum is less. There are other facts to be learned about the pendulum ex-

perimentally, in regard to the influence of the mass of the bob, the length of its path, or the *amplitude* of swing, and the exact ratio of time of swing to length of pendulum. They will not be given here, as they are easily deduced from observation in simple experiment.

A *complete* or *double* vibration is the swing between two successive passages of the pendulum *in the same direction* past any given point. That is, from the centre to the extreme right, to the extreme left and back to the centre again, forms a complete vibration. A *single vibration* is the swing between two successive passages in opposite directions past the vertical, or half a complete vibration.

Any material pendulum with which we can have to do is made up of an infinitely large number of simple pendulums rigidly connected together. Such a pendulum is called a *compound* pendulum. Evidently, there will be some point in it so situated that a particle there swings in just the same time as if it were freed from the other parts of the pendulum. This point is called the *centre of oscillation*. The particles above this centre are forced to move more slowly, and those below this centre are forced to move more quickly than they would if they were free.

EXPERIMENT.

Apparatus.—Stand, or support, for pendulum; metre stick; light cord; two bobs, of different masses.

1. Place the stand on the table. Adjust the two pendulums to be about one metre long and of the same length, measuring from the point from which the pendulums swing to the middle of the bob. Draw them aside together by the metre stick or any other convenient means, and release them together. Let them vibrate for some little time, and note any difference in their behavior. What is the effect of changing the mass of the bob?

2. Choose a pendulum with a bob of convenient mass—

one about three centimetres in diameter would answer well. Make its length as nearly as possible one metre. Draw it aside about six inches so that it will swing through an arc of about one foot. Count the single vibrations. Note the time of release, by your watch or the laboratory seconds clock. At the completion of the one hundredth single vibration note the time again, and record the number of seconds which have elapsed. This number divided by one hundred gives the time of a single vibration. Then draw the bob aside twice as far as at first, and find in the same way the time of one hundred vibrations. A comparison of these two values will show the effect of amplitude of swing. What difference does it make whether the pendulum swings through a very small arc, or a moderately large one?

3. Adjust the length of the pendulum to just one-half its former value and find the time of a single vibration by the method already described. Then diminish the length again by one half and find the time of a single vibration. Record your observations in the following form :

Length.	Length of Arc.	Time of 100 Vibr.	Time of Single Vibr.

Determine from these results the relation between length of the pendulum and time of one vibration. That is, is the time proportional to the length directly, the square root of the length, or the square of the length?

Take other values for the length and find the time of vibration. Make as many as ten determinations, using more of the smaller lengths than of the greater. From these results, plot a curve showing the relation between time of vibration and length of pendulum.

EXERCISE XV.

FLUID PRESSURE.

We have dealt, so far, with rigid bodies, in which the particles are so firmly bound together that the body has both *size* and *shape*. In a *fluid*, on the other hand, the particles move with considerable freedom past each other. If the fluid were a *perfect fluid*, the particles would be perfectly free to move, with no opposing force of the nature of friction. The shape of a perfect fluid could therefore be altered by the application of any force, however small, and there would be no resistance to the separation of any portion from the rest of the mass. In nature we never meet with fluids in which there is absolutely no resistance to the motion of the particles past each other. Some fluids, such as tar, molasses, and shoemaker's wax, offer considerable resistance to a change of shape, while others, such as water and alcohol, will change their shape much more quickly under the action of a given force. Fluids which offer a resistance to change of shape are called viscous fluids.

Ice is an example of a rigid body ; while water and steam are fluid. Here we recognize another distinction. Although both water and steam are called fluids, a substance of the nature of water, which has a pretty constant volume, whatever the pressure, is called a *liquid* ; while a fluid of the nature of steam, which will change its volume according to the pressure applied, is called a *gas*.

A *perfect liquid*, then, is a fluid whose total volume cannot be changed by the application of any force, however great, although its shape can be changed by any force, however small.

A *gas* is a fluid whose shape and total volume are both changed by any change, however small, in the applied force.

A perfectly rigid body, then, has a definite size and a definite shape.

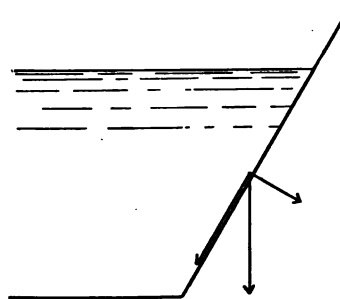
A perfect liquid has a definite size but no definite shape.

A perfect gas has no definite size and no definite shape.

In the discussion of liquids, they will be considered incompressible.

If we stand a solid cylinder on its end, the pressure on the base will be equal to the weight of the cylinder. From the nature of the solid, there will be no pressure on the sides due to its weight. Suppose, now, we attempt to stand a liquid cylinder on end in the same way. The pressure on the bottom would be that due to the weight of the liquid. But as the particles slide easily past each other, the force of gravity will cause it to change its shape instantly; and we must surround it with solid walls to keep its shape. There must, then, be pressure on these walls which balances the attraction of gravity; and every small area of wall must support the weight of the column of liquid above it of the same area of cross-section.

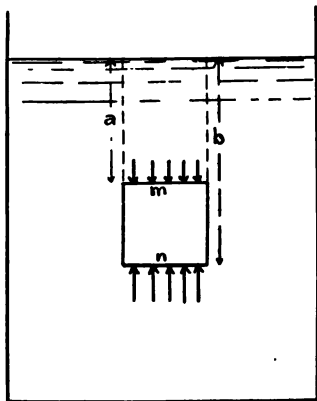
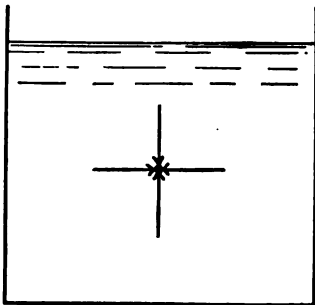
For the same reason, the pressure must be perpendicular to the surface. If it were not, the force could be resolved



into two forces, one at right angles to the surface and one parallel to it. The component parallel to the surface, if unbalanced, would cause motion of the liquid along the surface, as the particles move freely. The pressure is really exerted in all directions; and the only force

which is unbalanced by other liquid pressures, is that perpendicular to the wall. This is balanced by the reaction of the wall.

If we have a small particle suspended in a liquid, there is an equal pressure exerted at every point of the surface, and the particle therefore does not move. If the particle is a body of appreciable size, such as a cubical block, the downward pressure on the top is that due to the column of liquid of the size of the upper face of the block, and of the height a ; while the upward pressure on the lower face is that due to the column of the height b .



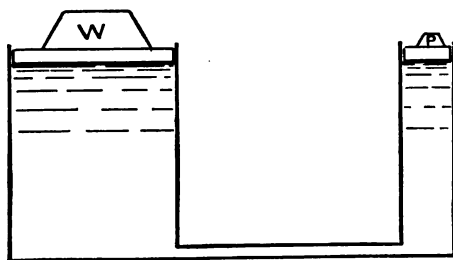
So far as the liquid alone is concerned, there is, then, an excess of upward pressure; and if the block is assumed to have no weight it must move upward under the action of the unbalanced upward pressure. If the block weighs the same as an equal volume of liquid, the downward pressure on the dividing surface, n , is the weight of the column of liquid, a , plus that of the block. It is therefore the same as the pressure of a column of liquid of height b , and the upward and downward pressures at n balance, so that the block does not move. If the block is heavier than an equal volume of liquid, the downward pressure at n is greater than the upward pressure, and the block must sink until it reaches such a point that the upward reaction is equal to the downward force. This is usually the bottom of the vessel.

Wherever the block is, and whatever its weight may be, the difference between the downward pressure and the up-

ward pressure on the block must be equal to the weight of a volume of liquid equal to the volume of the block.

Owing to the nature of a liquid, pressure applied to any point of it is transmitted undiminished in all directions. If we should attach to a tube a rubber bag, and slip through the tube a rigid, heavy rod, the rubber bag would extend itself downward until the elastic force due to the stretching of the rubber balanced the weight of the rod. If, now, we remove the rod and pour in a liquid, the bag does not stretch, as before, in one direction only, but assumes a spherical shape, stretching until the force of elasticity balances the pressure of the column of liquid. In this case, the pressure on each area of surface of the bag equal to the area of cross section of the tube has to balance the pressure due to the weight of a column of liquid of height equal to the vertical distance from the area in question to the top of the liquid column.

This principle is used in most systems of water supply. A stand pipe, of moderate cross-section, supplied by a pump, is kept in connection with the pipe system, and causes a pressure on each area of pipe surface equal to the weight of a column of water of that cross-section and of



the height of the water in the stand pipe.

The hydrostatic or hydraulic press is another example of the application of this principle.

A large and a small cylinder are connected by a pipe, and filled with water. When the smaller piston has a force applied to it this force is transmitted in all directions, into the pipe and the larger cylinder. There is, then, on every small area of the large piston, a force equal to that exerted

by the same area on the small piston ; so that the total force on the large piston is as many times greater than that exerted by the small piston as its area is greater than the area of the small piston. The *work* done by one piston, however, is equal to that done upon the other.

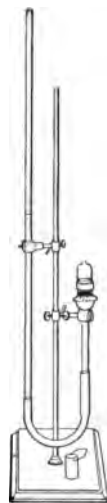
EXPERIMENT.

Apparatus.—Thistle tube ; long glass tube ; 25 cm. of rubber tubing ; retort stand ; sheet rubber ; disk of wood or metal ; weights ; metre stick.

Two students may work together on this experiment.

Tie the sheet rubber tightly over the large end of the thistle tube so that water will not leak through. Connect the long glass tube and the thistle tube by means of the rubber tubing, and support both tubes by separate clamps on the same stand. Fill with water until it stands in both tubes at the level of the rubber diaphragm. The air may be removed from the thistle tube by inverting it and shaking slightly.

Place the metal disk, which should be large enough to completely cover the mouth, upon the thistle tube, and place upon it the 50-gramme weight. Then pour water slowly into the long tube until the disk just begins to rise from the edge of the thistle. Adjust, by raising or lowering the long tube, until the disk is just touching, but not resting upon the edges of the thistle. Some practice is necessary to perform this adjustment correctly, but it can be done with considerable accuracy. The diaphragm must be flat, and touching the disk throughout its surface, or some of the upward pressure will be taken by the elasticity of the rubber ; while if the disk is resting upon the rim of the thistle, some of the weight will be borne by it instead of the liquid.



Measure the height of the water column above the table and the height of the diaphragm above the table. The difference between these heights gives the length of liquid column effective in producing the pressure.

Measure carefully the diameter of the mouth of the thistle. Make several measurements, of different diameters, and from their mean calculate the area of the diaphragm. Weigh the metal disk and record its weight.

Proceed similarly with 100 grammes, 150 grammes, and 200 grammes, recording every observation as it is made.

Make your record in the following form :

Height Upper Surface.	Height Diaphragm.	Diff. in Level.	Weight of Disk.	Weight Applied.	Total Weight.	Area of Diaphragm.	Press. per Square Cm.	Press. p. Sq. Cm. Diff. in Level.

From the mean of these results, what would be the pressure exerted on one square centimetre of surface by a column of water ten metres high ?

In the arrangement of apparatus as described, the conditions are the same as in a vessel of water, at a depth below the surface equal to the difference in level of the water surfaces. What, then, is the relation between pressure and difference of level ? Plot a curve showing this relation.

EXERCISE XVI.

DENSITY.

The *density* of any body is the mass contained in a unit volume of that substance.

The numerical value of the density of any body will be different for different systems of units. Thus the density of water is about 62.5 lbs. per cubic foot or 1 gramme per cubic centimetre. These values differ very greatly ; but we shall concern ourselves only with the metric system. We have, so far, neglected the effect of change of temperature upon a liquid. Most substances, in whatever state they may be, increase in volume as they are heated. One most notable exception to this rule, however, is water. If water is heated, from the melting point of ice, it gradually diminishes in volume until a temperature of about 4° Centigrade, or about 39.1° Fahrenheit, is reached. As it is heated above this point, the volume increases.

There is one effect, in nature, of this peculiar behavior of water, which is most important. As the water grows colder, from the normal temperature, it grows more dense ; and the denser parts sink to the bottom, forcing the less dense portions to the top according to the principles explained in the last exercise. When the temperature of the whole has reached 4° C., however, any further cooling diminishes the density. Therefore, as the cooling usually takes place at the top, the water at the bottom remains at a temperature of 4° while the top grows colder. Finally, the ice forming at the top, any forms of life in the water are protected from destruction except when the cold is so intense as to freeze the water to the bottom.

EXERCISE XVII.

SPECIFIC GRAVITY.

It is convenient, in dealing with the densities of substances, to be able to state the ratio of the density of each substance to that of some substance taken as a standard. We do not then have to know anything about the system of units used, as this ratio is simply a *number*. It is called the *Specific Gravity*—usually written *Sp. Gr.*

The specific gravity of a given substance is the number expressing the ratio between the weight of any volume of the substance and the weight of an equal volume of some substance taken as a standard.

Water is usually taken as the standard substance, at a temperature of 4° C., and all solids and liquids are referred to it. For gases, air is the standard, at the freezing temperature and under the usual atmospheric pressure.

In the metric system, although density and specific gravity are entirely different things, their numerical values are the same ; for the density of water at the standard temperature is unity, a cubic centimetre of pure water, at that temperature, having a mass of one gramme.

A knowledge of the specific gravity of substances is useful in determining the weights of known volumes of bodies which cannot conveniently be weighed ; also in determining whether a given body will sink or float in a liquid and the weight which it will support when floating.

Below are given the approximate specific gravities of some important substances.

Pt	21.5	Glass (crown) ..	2.5 to 2.7
Au	19.25	Glass (flint)	3.0 to 3.5
Hg	13.6	Oak	.7 to 1.
Pb	11.3	Alcohol	.8
Ag	10.5	Cedar	.6
Cu	8.9	Poplar	.4
Brass	8.4	Cork	.24
Fe	7.8		
Zn	7.1		

To find the specific gravity of any substance with respect to water, we have to compare the weight of the substance with that of an equal volume of water. There are three principal methods of doing this :

1. By the specific gravity bottle.
2. By the hydrostatic balance.
3. By hydrometers. { Nicholson.
Beaumé.

The specific gravity bottle is a bottle capable of holding a constant quantity of liquid, closed by a ground-glass stopper which has a small hole through it to allow the superfluous liquid and enclosed air to escape when the stopper is pushed in.



We can find by the specific gravity bottle, the sp. gr. of a liquid or of a solid.

Let the weight of the bottle alone be w .

Let the weight of the bottle filled with water be w' .

Let the weight of the bottle filled with given liquid be w'' .

Then $w' - w$ = weight of water filling the bottle,

$w'' - w$ = weight of liquid filling the bottle.

$\therefore$ as these volumes are equal,

$$\frac{w'' - w}{w' - w} = \text{sp. gr. of liquid required.}$$

To find the specific gravity of a solid which is insoluble in water :

If the solid is of such a shape as not to go into the bottle, break it into pieces. Call the total weight of the solid W .

Fill the bottle with water, drop in the solid, push in the stopper, and weigh. Call the weight w''

$w' + W$ = weight of bottle filled with water, and solid outside.

w'' = weight of bottle and water and solid inside.

Then, as the solid must have pushed out of the bottle a quantity of water equal to its own volume, the first weight will differ from the second by the weight of the water displaced.

$w' + W - w''$ = weight of water displaced.

Then, as the volume of the solid is the same as that of the displaced water,

$$\frac{W}{w' + W - w''} = \text{sp. gr. of solid.}$$

If the solid would be in any way affected by water during the experiment, it must be placed in some other liquid which does not affect it, and the specific gravity of this liquid found in the manner already described. The specific gravity of the solid with reference to water can then be calculated from these results.

EXPERIMENT.

Apparatus.—Specific gravity bottle ; balance and weights ; distilled water ; metal cylinders ; piece of sulphur ; bits of lead ; a liquid.

1. Find by the methods just described the specific gravity of each substance furnished for that purpose. Weigh the bottle, dry. Fill the bottle with distilled water, take its temperature, push in the stopper carefully, getting out all the air bubbles. Do not hammer in the stopper, as it will chip the edges or break the bottle. Wipe the outside dry.

The bottle should be kept in the hands as little as possible, as the heat of the hand causes the water to expand. Weigh, and record.

Empty out the water, dry the bottle carefully, both inside and outside. Fill with liquid in the same manner as before, and weigh.

Record observations as follows :

Weight of bottle and water,	
Weight of bottle alone,	
Weight of water alone,	_____
Weight of bottle and liquid,	=====
Weight of bottle alone,	_____
Weight of liquid alone,	=====
Weight of liquid	=====

$$\text{Sp. Gr.} = \frac{\text{Weight of liquid}}{\text{Weight of water}} = \frac{\text{_____}}{\text{_____}} = \text{_____}$$

2. Find the specific gravity of each of the solids by the method already described. Use the same precautions as in 1, and find the weights in the same way. The weight of the bottle alone is not needed in this experiment, as we have to deal with differences only. Any measurements made in part 1 which are needed may be taken from that part. Record your observations and results in the following form :

Substance.	W .	Weight Bottle Filled w. Water, w' .	Bottle, Water and Solid Inside, w'' .	$W + w' - w''$.	Sp. Gr. $\frac{W}{W + w' - w''}$.

EXERCISE XVIII.

SPECIFIC GRAVITY.—(*Continued.*)

HYDROSTATIC BALANCE AND HYDROMETERS ; BALANCING COLUMNS.

In our consideration of liquids we saw that any body submerged in a liquid is under an excess of pressure upward due to the weight of a volume of the liquid equal to the volume of the body. If then, a body be weighed while suspended in a liquid, it will appear to lose in weight by an amount just equal to the weight of its own volume of the liquid. That is, it is buoyed up by the liquid to this extent. This is called *Archimedes' principle*. If we find the weight of a body in a vacuum and then find its weight when suspended in water, the difference will give the weight of a volume of water equal to the volume of the body. We shall then have all the necessary data for determining the specific gravity of the body.

EXPERIMENT.

Apparatus.—Balances and weights ; thread for suspending body ; three metal cylinders ; tumbler of water ; piece of wood.

1. For a body that sinks in water.

Weigh the body in the air. Suspend the body by a thread from the balance arm so that it hangs wholly immersed in water, but not touching the sides of the tumbler. Find its weight so suspended.

Let W be the weight of the body in air.

Let w be its apparent weight in water.

Then $W - w =$ the weight of the water displaced.

$$\frac{W}{W - w} = \text{specific gravity.}$$

Find the specific gravity of each substance in this way, and record your observations and results in the following form :

Substance.	Weight in Air = W .	Weight in Water = w .	$W - w$.	$\frac{W}{W - w} = \text{Sp. Gr.}$

2. For a body that floats in water.

In this case the body must be attached to some other body that will sink it.

Then, if W is the weight of the body alone,

W' is the weight of the sinker alone,

w is the weight of the body and sinker in water,

w' is the weight of the sinker alone in water,

the weight of the water displaced by the sinker and body together is $W + W' - w$, and the weight of the water displaced by the sinker alone is, as in part 1, $W' - w'$.

Then the weight of the water displaced by the body alone must be the difference between these two, or $W + W' - w - (W' - w')$

$$\begin{aligned} &\text{or } W + W' - w - W' + w' \\ &= W + w' - w \end{aligned}$$

and the specific gravity of the body = $\frac{W}{W + w' - w}$.

We do not need, therefore, to find the weight of the sinker in air.

Weigh the wood in the air. Then weigh the sinker in water. Fasten the two together and weigh in water. De-

termine the specific gravity from these observations, which should be recorded as follows :

Sub- stance.	Wt. in Air, W .	Wt. of Sinker in Water, w' .	Weight Body + Sinker in Water, w .	$W + w' - w$.	Sp. Gr. $\frac{W}{W + w' - w}$.

Repeat with each substance furnished.

HYDROMETERS.

If any body is floating in a liquid, it sinks to such a depth that the weight of the water which it displaces is just equal to its own weight. Suppose then, we have a body of convenient shape floating in water, and note the point to which it sinks. If we now place it in some other liquid, such as alcohol, it will sink deeper, because it takes more of the alcohol than of the water to make up a given weight. By using liquids of known specific gravities, we could find exactly what value corresponded to each depth of flotation, and we might put upon the body marks by which the specific gravity could be read off directly. Such an instrument is called a *Hydrometer*; and the most common form is used in the way just described. The instrument consists of a glass stem ending in a bulb. The shape of the hollow portion is such as to give it the desired buoyancy, and the lowest bulb is loaded with mercury or lead to make it float upright. To determine the specific gravity of a liquid, this hydrometer is simply immersed in the liquid until it floats, and the sp. gr. read off directly from the graduations on the stem, the value of these graduations having been previously determined, once for all.

Suppose, now, that instead of this form of hydrometer, we take a tube, properly loaded, so that it shall float up-

right, and so arranged that weights can be added to it or taken off. Let us then so weight it, in every case, that it always sinks to the same mark. Then the displacement will be exactly the same in each case, and the weight of the hydrometer, plus the weights added, will just equal the weight of the displaced liquid. The weight which we must add will be less as the sp. gr. of the liquid is less.

Let the weight of the hydrometer itself be W .

Let the weight added when it floats in water be w .

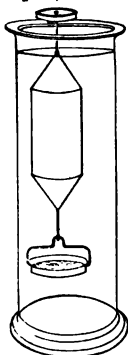
Let the weight added when it floats in the liquid be w' .

As the volume displaced is constant, the sp. gr. of the liquid will be simply the ratio of the total weight in one case to that in the other, or

$$\text{Sp. gr.} = \frac{W + w'}{W + w}.$$

A common test-tube may be very easily used as a hydrometer in this way.

The Nicholson hydrometer is constructed on this principle, with an additional device for finding the sp. gr. of solids. It consists of a hollow metal vessel supporting, by a fine stem, a flat pan in which weights may be placed. From the lower end hangs a small loaded basket in which a solid of suitable size may be placed. On the fine stem is a reference mark, and such weights are added as will just sink the instrument to the reference mark. It will thus displace always a constant *volume* of liquid. The common hydrometer, on the other hand, displaces a constant *weight*.



The method of using this hydrometer to find the specific gravity of a liquid has been described. To find the specific gravity of a solid proceed as follows :

Place the hydrometer in water, and weight the pan until it sinks to the reference mark. Remove the weights, place the solid in the upper pan, with the hydrometer floating in

water, and add weights until it sinks to the reference mark. Remove the weights, place the solid in the basket at the bottom, and add weights in the pan until it sinks again to the mark.

Let the weight to sink the hydrometer alone = w .

Let the weight to sink the hydrometer + body in pan = w' .

Let the weight to sink the hydrometer + body in basket = w'' .

Then, evidently, $w - w' =$ weight of body in air,
and $w - w'' =$ weight of body in water.

$\therefore w - w' - (w - w'') =$ weight of water displaced
 $= w - w' - w + w'' = w'' - w'.$

$$\text{Sp. gr.} = \frac{\text{Weight of body in air}}{\text{Weight of water displaced}} = \frac{w - w'}{w'' - w'}.$$

EXPERIMENT.

Apparatus.—Jar of water; test-tube; small shot; balances and weights; liquids for determination of specific gravity.

Immerse the test-tube in water, having made a mark upon it at a convenient height. Some care should be taken that the test-tube floats upright. A very thin rubber band may serve as a mark, or a slight scratch with a file. Be careful not to break the tube in making the mark. Add shot until the tube is immersed to the mark. Remove it from the water, wipe it dry, and weigh. Remove the shot, immerse in the liquid, and add shot until the tube again floats with the top of the liquid just reaching the mark. Wipe dry, and weigh again as before. Then, as the total weight of the tube, in each case, is the weight of the liquid displaced, the required specific gravity of the liquid

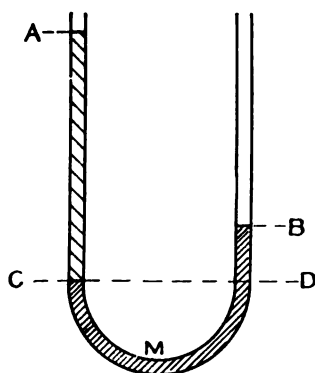
$$= \frac{\text{Weight in liquid}}{\text{Weight in water}}.$$

Record as follows :

Liquid.	Weight in Water.	Weight in Liquid.	Sp. Gr.

BALANCING COLUMNS.

If two liquids, which do not mix, are poured into the two legs of a bent tube, they will come to rest with their common surface at some point whose position will depend on the relative densities of the liquids. It does not matter whether the tube is of uniform cross-section or not. For,



considering the dividing surface at *C*, the upward pressure on that surface is the pressure due to the weight of the column of liquid having that cross-section and a height *BD* above the level of *C*. This follows from the properties of liquids. The downward pressure on the surface *C* is that due to the weight of a column of cross-section *C* and height *AC*. The upward pressure on the surface *C* is that

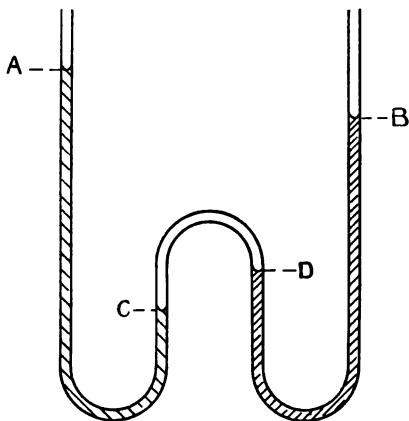
due to the weight of a column of cross-section *C* and height *BD*; for the columns *CM* and *DM* balance each other. As the liquids are in equilibrium these pressures must be equal. Hence the column of length *BD* and cross-section *C* must weigh the same as the column of length *AC* and cross-section *C*; and the densities must be inversely as the heights of the liquids above the level of the dividing surfaces. That is,

$$\frac{\text{Density of } B}{\text{Density of } A} = \frac{AC}{BD}.$$

Now, if one of these liquids is water, we have a ready method of finding the sp. gr. of a liquid which does not mix with it by direct measurement of a length. The heavier liquid must, of course, be poured in first.

Two liquids which do mix may be compared by an extension of this same principle.

Bend a tube into the form shown in the diagram, and pour in the liquids as before, the portion *CD* being filled with air. The air serves to keep the two liquids separate and to transmit the pressure. The air itself is so light that we can neglect any pressure due to difference of level of *C* and *D* in the air column. Then the pressure upward on *C* is that due to the weight of a column of height equal to the difference of level between *A* and *C*; and the upward pressure on *D* is, in the same way, that due to the weight of column of height equal to the difference of level between *B* and *D*. As the pressure is transmitted in all directions through the air and through the liquids, it does not matter whether or not the cross-section of the tube is uniform. The specific gravities of *A* and *B* will be inversely as the differences of level, *AC* and *BD*.

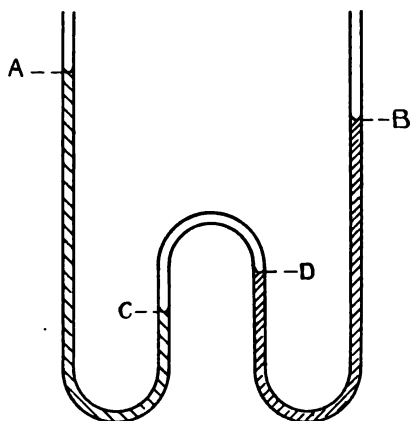


EXPERIMENT.

Apparatus.—Glass tubing, about 8 mm. diam., 75 cm. long; retort stand with clamps; metre stick; liquids for determination of specific gravity.

Bend a glass tube into the shape shown. Hold the

thumb tightly over one end and pour water into the other, raising the thumb very slightly to allow the air to escape gradually, so that the water shall nearly fill the lower part of the U and stand near the top of the longer leg. Then put the other thumb over the open end into which the water was poured, and pour the liquid whose sp. gr. you are to find into the other end, in the same way, until suitable levels have been reached, allowing the water to overflow if



necessary. A little practice will make this easy. Clamp in the stand in a nearly vertical position. Then measure, *vertically*, from the table, the heights of *A*, *B*, *C*, *D*. *AC* and *BD* will be the lengths of columns and, if *A* is the water column, $\frac{AC}{BD} = \text{sp. gr. of the liquid.}$

Find, in this way, the sp. gr. of each liquid furnished, recording observations as below :

Liquid.	Height <i>A</i> .	<i>C</i> .	<i>B</i> .	<i>D</i> .	<i>AC</i> .	<i>BD</i> .	$\frac{AC}{BD}$

EXERCISE XIX.

GASES ; THE BAROMETER.

It has been stated that a certain quantity of gas will readily change not only its shape, but also its volume, under slight changes in force applied to it. If we have a certain amount of air confined in a bag from which it cannot escape, we can, by applying weights to the bag cause the air to diminish in volume. Every additional weight applied diminishes the volume by a certain amount, proportional to the weight, and we know from experience that the pressure exerted by the gas increases as its volume is lessened. In a *perfect gas*, the volume is inversely proportional to the pressure exerted by it, or, in other words, the product of the volume and the pressure is a constant quantity which depends upon the temperature of the gas. If we have a cubic metre of air, then, exerting a pressure of 1,000 grammes per square centimetre and if we double that pressure, making it 2,000 grammes per square centimetre, the volume will be reduced to one-half its former value, or one-half a cubic metre. This law is known as Boyle's law or Mariotte's law. A gas which follows this law exactly is called a *perfect gas* ; but such substances as air, hydrogen, and oxygen, may without appreciable error be treated as though they followed the law exactly.

If we take a closed vessel, filled with air, and attempt to find the weight of the air by means of an ordinary balance, used in a room in the usual manner, we fail to get any result. For we have here the case of a body immersed in a fluid of the same density, and the upward pressure upon the vessel

because of the buoyancy of the surrounding air is just equal to the downward pressure due to the weight of the inclosed air. If, however, we put the balance under such conditions that the air can be taken away from about it, the arm supporting the vessel of air immediately falls, showing that the air does actually weigh something. The weight of the atmosphere, therefore, extending, as it does, many miles above the surface of the earth, must be sufficient to cause a great pressure upon all bodies at the earth's surface; and the only reason that this pressure is not more often recognized in our daily experience is that it is exerted in all directions, and upon the interior of bodies as well as upon the outside, so that it is, in almost every case, balanced, and none of its effects is apparent.

Let us take a glass tube, about eighty centimetres long, closed at one end and made with stout walls. We fill this with mercury, using considerable care to get out all air-bubbles and not to let the mercury fall too sharply against the glass. We then place the finger over the open end; and inverting the tube and immersing the open end in a dish of mercury, remove the finger. The column of mercury in the tube falls somewhat, vibrates up and down for a while, and finally comes to rest with its surface about 76 centimetres above the level of the mercury in the dish. There is a considerable space between the top of the mercury and the closed end of the tube, and this space contains—what? If we have taken out all the air-bubbles, it contains nothing unless a little of the mercury has evaporated into it.

This experiment is called the "Torricellian experiment," and the space above the mercury a "Torricellian vacuum." What keeps the mercury up in the tube? We know that, as the mercury is very heavy, the pressure at the base of the column, due to its weight, must be considerable; and this pressure is transmitted undiminished through the fluid mercury, so that we know there must be a great upward pressure on the dividing surface between the mercury and

air. The whole system is in equilibrium, and the only thing which can balance this upward pressure is the downward pressure of the atmosphere due to its weight. Therefore a column of the atmosphere, of a given area of cross-section, say 1 centimetre square, must weigh the same as a column of mercury 1 centimetre square and 76 centimetres high.

If the sp. gr. of mercury is 13.596, and the height of mercury column supported by it is 76.0 centimetres, what is the pressure of the atmosphere?

An instrument arranged as described serves to measure the pressure of the atmosphere, and is called a "barometer." The atmospheric pressure varies continually, being in general less when the air contains a large quantity of vapor, and changing also with the currents set up in the upper air. All forms of mercurial barometer are simply modifications of the Torricellian experiment.

Of course, as the mercury in the tube falls, the level of the mercury in the cistern rises. The difference in level is what indicates the atmospheric pressure, and if we wish to put permanent graduations on a barometer so that the height of the column can be read off directly, we must allow for this change of level of the mercury in the cistern.

In the "Cistern barometer" the area of the surface in the cistern, or open vessel, is made so large that the change in level will be very slight for a considerable change in the tube. This is not strictly accurate, but is sufficiently so for ordinary purposes.

For more accurate measurement, the form is modified in this way. The cistern is made with a leather bottom, and a screw presses against this leather. By turning the screw, the level of the mercury in the cistern can be changed. Just above the surface of the mercury in the cistern is a little ivory point; and from this point the scale above is graduated. In reading the instrument, the screw is turned one way or the other, until the surface of the mercury in the cistern just touches the ivory point. Then the position

of the top of the mercury column is read off from the scale, giving the exact difference of level. This form of the instrument is called the "Fortin" barometer. It is used in the Signal Service and for all accurate measurements.

Another form is the "Siphon barometer." This consists of a U tube, one leg being much shorter than the other, and the longer leg closed. The difference of level, between the mercury in the short and that in the long leg, is the height of the barometric column. The graduations are usually made from the middle, and run both ways, so that adding the two readings together gives the proper value.

If, instead of mercury, a different substance is used, of smaller specific gravity, the height of column which the atmospheric pressure will support will, of course, be greater.

If water is used, the sp. gr. of mercury being 13.596, we must have a column 13.596 times as long to balance the atmospheric pressure. Calling the normal height of mercury column 76.0 cm., the water barometer would stand at a height,

$$13.596 \times 76.0 = 1033 \text{ cm. (or about } 10\frac{1}{3} \text{ metres).}$$

There are several simple machines, depending for their operation upon atmospheric pressure, which deserve description. The most common are

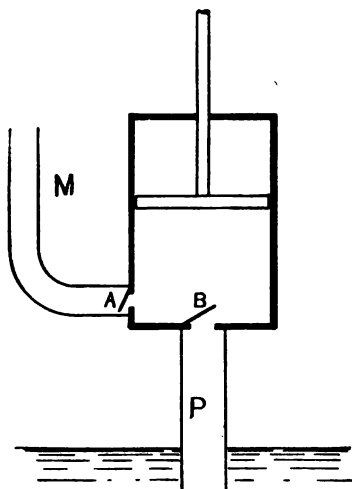
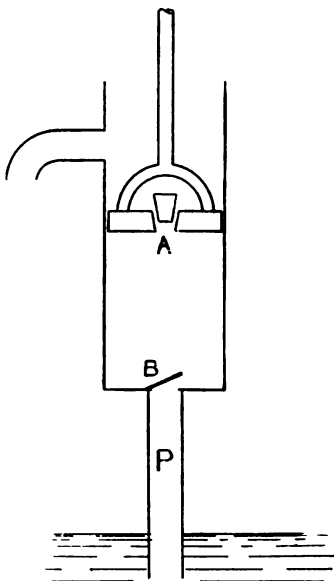
The suction pump ;

The force pump ; and

The siphon.

The suction pump is constructed on the plan indicated in the diagram. A piston, having in it a valve *A*, moves up and down in the box or cylinder. Connection is made with the water below by means of the pipe *P*, having at some point a second valve *B*. Both valves open upward, and may be of any pattern. In the drawing, *A* is shown as a conical valve, and *B* as a disk valve. Suppose the pump is started with the piston up, and filled with water above the piston. As the piston moves downward, the valve *B* is closed and the valve *A* opened by the pressure. The water

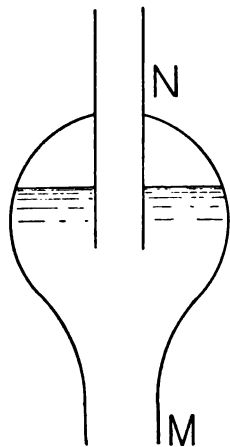
in the barrel then passes through *A*, above the piston. When the piston is raised, a partial vacuum is formed in the barrel, the atmospheric pressure forces the water from the reservoir up the pipe, through *B*, into the barrel, while the water above the piston closes valve *A* and is lifted until it runs out at the spout. Of course *A* and *B* are not open at the same time, *A* opening on the down stroke, and *B* on the up stroke. As the atmosphere will sustain a column of water not higher than about 10 metres, the distance between the level of the water supply and the piston must be less than this or the pump will



refuse to operate. Practically the various leakages in the apparatus diminish this possible distance to about 9 metres. The height through which the water may be lifted, however, above the piston is limited only by the strength of the parts and the available power.

In the force pump the piston is solid, and instead of a spout, a pipe, *M*, leads to the vessel which is to be supplied with water. The valve *A* opens outward from the

barrel, and the other parts are as in the suction pump. On the up stroke, the weight of water above closes the valve *A*, and water is forced into the cylinder, through *B*, as in the suction pump. On the down stroke, the pressure in the cylinder closes valve *B* and opens *A*, and the water in the cylinder is forced out through the pipe *M*. The pressure on the down stroke must, of course, be sufficient to overcome the pressure of the water in *M* against *A*, which is generally considerable, and the valve *B* must not be more than about 9 metres above the level of the water in the cistern, as in the suction pump.

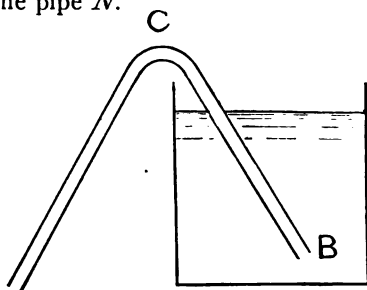


In a force pump constructed in this manner, the flow of the water through the pipe *M* would be intermittent, and the apparatus would be subject to a hard blow on the change of motion of the piston. To overcome this defect, an air-chamber is provided, into which the pipe *M* leads, as shown in the diagram. At each downward stroke water is forced into the chamber, compressing the air, which forms a sort of spring cushion; and the expansive force of this compressed air keeps up

a continuous flow through the pipe *N*.

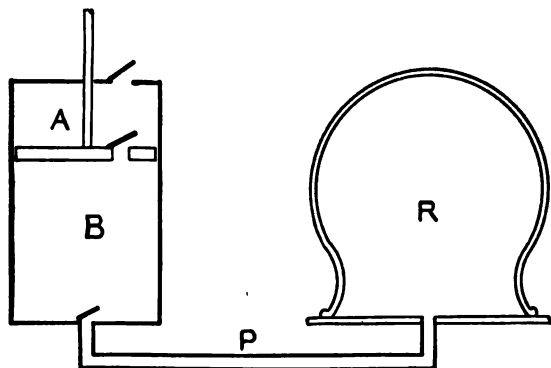
The siphon consists of a bent tube, having one leg longer than the other. Let us assume it filled with liquid and the shorter leg immersed in the liquid. The weight of the liquid in the longer leg causes it to flow out, *A*

so that the pressure at *C* is diminished. The pressure of the atmosphere upon the surface of liquid in the vessel



causes it to flow into the end *B*, and a continuous flow is kept up until the level of the liquid falls below *B*, when air enters and the flow of liquid stops. The siphon is very useful in transferring liquid from one vessel to another, as, when once started, it continues in operation until the higher vessel is nearly emptied.

The mechanical air-pump is constructed on much the same principle as the suction pump, with the addition of another valve, opening outward, in the spout. When the piston is raised, its valve is closed, the air in *A* is forced



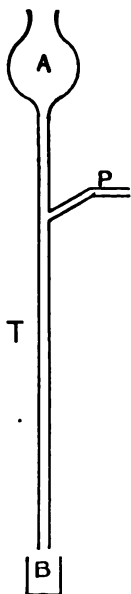
out through the valve above, and the air in *B* is rarefied. The expansive force of the air in *R* then opens the valve at the bottom of the cylinder, and the air which formerly filled *R* and the connecting pipe *P*, fills *R* and *B* and *P*, its pressure being diminished as its volume increases. The downward stroke of the piston opens its valve, closes the valve in *B*, and lets the air in *B* pass through into *A*, the upper valve also being closed by the greater pressure of the atmosphere above. This operation is repeated at each stroke, the air in *R* expanding each time so as to fill the cylinder also, and its pressure becoming less accordingly. Evidently, by this method the air can never be wholly removed from *R*, as only a certain proportion of it is carried away at

every stroke ; but its pressure can be very greatly reduced if the pump is carefully constructed and the valves are tight.

A higher degree of exhaustion can be obtained by the use of the mercury pump of Sprengel.

In this pump, mercury is allowed to fall from a vessel *A*, through the tube *T*, into a vessel below. A branch pipe *P* is connected permanently to the tube, and to the pipe *P* the vessel to be exhausted is attached. The mercury, in falling past the opening of *P*, entangles in its column portions of the air. There are fewer sources of leakage in this pump, and by keeping up the flow of mercury nearly all the air can be exhausted from the vessel attached to *P*.

The Bunsen filter pump operates on this principle, using water instead of mercury. It is usually operated from the city mains. Of course, in both the Sprengel and the Bunsen pumps, the pressure at the outlet must be greater than the atmospheric pressure, or the pump will not operate.



EXPERIMENT.

1. *Apparatus*.—Stout glass tube closed at one end ; open dish (“crystallizing” dish) ; mercury ; fine iron wire.

Two students may work together on this experiment.

Fill the tube carefully and completely with mercury, removing air-bubbles by means of the wire. (Iron wire must be used because it does not form any combination with the mercury.) Partially fill the dish with mercury. Close the open end of the tube with the finger or thumb, holding it firmly to make sure that no mercury escapes. Invert the tube, place the open end, covered by the finger, under the surface of the mercury in the dish, and remove the finger.

Note the behavior of the mercury column, as the tube is held vertical and as it is slightly inclined from the vertical. Measure the vertical distance between the two mercury surfaces, in each position of the tube.

2. *Apparatus.*—Tall jar of water ; long tube, closed at one end.

Invert the closed tube and force it, mouth down, into the water. You will see that the water gradually rises in the tube, but that the level inside is lower than that outside. This arrangement forms substantially a diving bell. How do you account for the action of the water and air ?

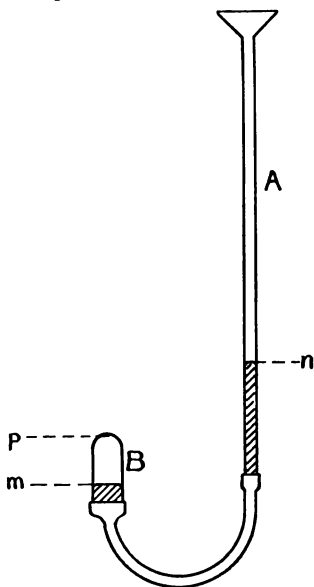
3. *Apparatus.*—Funnel tube with long stem ; short, stout glass tube, closed at one end ; stout rubber tubing ; mercury ; metre stick ; tall jar ; long glass tube, and rubber stopper to fit ; retort stand and clamps.

Two students may work together on this experiment.

A. Pressures Greater than One Atmosphere.

Connect the short tube to the funnel tube by the rubber tubing, as shown. Hold the apparatus upright by means of a retort stand. The joint *B* may be made tight by fastening the supporting clamp at that point.

Pour mercury into the funnel tube until the mercury surface shows above the joint at *B*. Air may be passed either into or out of the short tube, by inclining the tube, until the two mercury surfaces stand at about the same height. The quantity of air must not be changed *during* any series of measurements. There is then a quantity of



air confined in the short tube, and it is subjected to atmospheric pressure plus the pressure of the mercury due to the difference in height $n-m$. Find the atmospheric pressure by reading the siphon barometer. The cross section of the shorter tube should be as uniform as possible.

Measure the height of the points p, m, n , from the table or the base of the stand. Then, assuming the short tube to be of uniform bore, the volume of the confined air is proportional to the distance pm . The pressure upon this air is proportional to $n-m+b$, where b is the height of the barometric column.

Pour more mercury into the long tube, and measure the new values of m and n . Make as many as five separate sets of measurements until the top of the longer column reaches nearly to the top of the tube.

If the air obeys Boyle's law, the volume occupied by it should be inversely proportional to the pressure upon it.

If a is the cross section of the short tube, the volume of the air is $a(p-m)$. As the mercury column, at the surface of separation, has the same cross-section, the pressure due to its weight is $a(n-m)d$, where d is the density of mercury. As a and d are constant quantities, and as we are dealing only with ratios, they may be neglected. Therefore, assuming a constant value for a , the product $(p-m)(n-m+b)$, should be very nearly the same for each set of measurements.

Record the observations in the following form :

p .	n .	m .	Barometer. b .	$n-m$.	$n-m+b$.	$p-m$.	$(p-m)(n-m+b)$.

If the number in the last column is not found to be nearly the same in each case, the shorter tube must be calibrated. That is, the ratio of the volumes contained in it

from the closed end up to each measured value of m must be found.

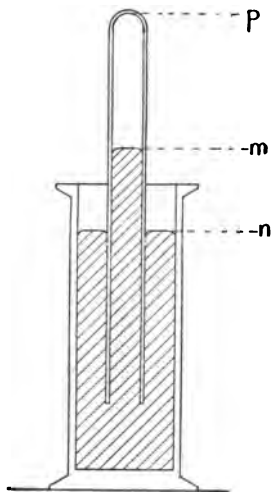
To do this, detach it from the rest of the apparatus. Weigh it empty. Fill up to the highest value of m , and weigh again. Then fill to the next value of m , and weigh as before. Repeat this for each value of m . The volume of the tube up to each point will then be proportional to the weight of mercury contained in it at that point. Then make new values showing the products of each weight by the corresponding height of mercury column, $n - m + b$. Enter in a table as follows :

Weight of Tube Empty.	m .	Weight when Filled to m .	Weight of Hg. Contained.	Weight $\times (n - m + b)$.

B. Pressures Less than One Atmosphere.

Put mercury in the tall jar. Push the long tube, open, nearly to the bottom of the jar, and close tightly with the rubber stopper. Raise it until the mercury inside is on a level with the mercury outside.

Measure the length of the air-column. Raise the tube somewhat and measure the heights of p , m , and n , from the table. Then the volume of the air is proportional to $p - m$, and the pressure upon the air is $b - (m - n) = (b + n - m)$, where b is the height of the barometer column. Make several determinations, raising the tube until the lower end is nearly



up to the surface of the mercury in the jar. Enter the observations as follows :

$p.$	$n.$	$m.$	$b.$	$b + n - m.$	$p - m.$	$(p - m)(b + n - m).$

The product given in the last column should be nearly the same in each case.

Note. In handling mercury, be careful not to spill it, as it is impossible to gather it up again, and it is expensive. Do not touch any gold to mercury, as it will form an amalgam and injure the gold.

EXERCISE XX.

HEAT.

According to the theory now most generally accepted as to the structure of matter, the smallest possible particle into which any substance, however complex, can be divided by the most perfect mechanical means is the molecule. The molecule of any substance can in turn be divided, by means other than mechanical, into its constituent elemental parts ; and each of these infinitesimal parts is called an atom. The molecule of wood, for instance, is the smallest particle which can exist, and still retain the properties of wood ; but it can be divided into several constituent elemental atoms, chiefly carbon, hydrogen, and oxygen, which had combined in certain definite proportions to form the molecule of wood.

The molecules of a substance are separated from each other by spaces which are considerable in comparison with the size of the molecules : and the molecules are at all times moving about through these spaces. It is the energy of this motion of the molecules which constitutes heat, and which gives rise to the sensation of heat when a body is touched. The degree of heat, or the temperature, depends on the violence of movement of the molecules, and the quantity of heat in any body is the total energy of motion of its constituent molecules.

If one body will communicate heat to another in contact with it, or near it, we say that the first body is at a higher temperature than the second.

Heat may be communicated from one body to another,

or from one part of the body to another part in three ways :

By conduction ;

By radiation ;

By convection.

In *conduction*, the heat travels along a body, or from one body to another in contact with it, one moving molecule giving up a part of its motion to the next, that molecule, in turn, communicating some of its motion to the next, and so on.

In the process of *convection*, a hot substance is moved bodily from one point to another, finally communicating part of its heat, by conduction, to another body.

Radiation is the sending out, from a hot body, of rays of heat, in straight lines in all directions.

When heat is applied to one portion of a metallic bar, we know that the part at a distance from the source of heat will in time become hot. When a teaspoon, for instance, is placed in a cup of hot liquid, the handle, although cold at first, and not in contact with the hot liquid, will soon become hot. This is an example of conduction.

If we put a beaker of water over a flame and watch it carefully, we shall soon be able to see that in some places streams of the liquid are rising from the bottom, while in other places streams are falling from the upper portions to take their places. This is the way in which most liquids acquire heat, and is an example of convection. Gases are heated almost entirely by convection. The heated portions leave the hot surface, if it is at the bottom, and cold portions, taking their place, are heated by conduction from the surface and make way in turn for new portions which are cold. This is the reason why confined bodies of air are such good insulators of heat ; why spaces stuffed with woolly substances which prevent the circulation of air will keep heat from passing through them.

The heat which we feel just outside the bulb of an incan-

descent electric lamp is communicated by radiation. As the bulb is very nearly emptied of air, conduction and convection are of little service in communicating heat ; and the heat which we feel is that which is sent out in straight lines in all directions, or *radiated*.

If we take almost any solid substance—ice is the most familiar example—and add to its store of heat, the first effect is to raise its temperature. This continues until the temperature of the ice has reached 0° C., when the temperature stops rising and the ice begins to melt. While the ice is melting, although we are still adding heat, the temperature remains constant. This process of melting or change of state from the solid to the liquid, is called *fusion*. The heat which has been added without producing any effect on the temperature has all been used in changing the substance from the solid to the liquid, and is called *Latent Heat of Fusion*. It is called “latent” because it is not made apparent in change of temperature.

If we now continue the application of heat to the water into which our ice has been transformed, the temperature rises pretty uniformly until it reaches 100° C. Here it stops rising, although the addition of *heat* continues, and the water changes into steam, that is, the substance changes from the liquid to the gaseous form. Here, again, a definite quantity of heat must be added—heat which is not made manifest in any change in temperature—to convert the liquid to a vapor ; and this heat is called the *Latent Heat of Vaporization*.

It is probable that any substance whatever can be made to take any or all of these forms by suitable conditions.

If we should now take the steam which has resulted from the ice with which we started, and abstract heat from it, we should change it back to water and then to ice ; and the amount of heat which we took away from it, in changing it back to its original condition, would be exactly equal to the amount which we added to it in the first process.

There is another phenomenon which is to be observed when a body loses or acquires heat. The body changes its volume, usually growing somewhat larger as its temperature rises. Water forms the most notable exception to this rule, as has been previously explained.

We have, as yet, developed no method of measuring heat, although we have been dealing with changes in the total quantity of heat in a body. We may measure heat in two ways: By the amount of ice which the heat will transform into water at the same temperature; and by the increase which it will produce in the temperature of a known mass of a given substance, such as water.

In either method, it is essential that we should have some means of measuring temperature.

There is no way of measuring temperature directly. It must be measured by its effects, and the most convenient effect for this purpose is the expansion of either solids, liquids, or gases. Any instrument for measuring temperature is called a *thermometer*.

The most convenient and usual form of thermometer is that in which the change of volume of mercury is used to indicate changes in temperature. The construction of the mercurial thermometer is, briefly, as follows: A glass tube, of very fine bore, has blown upon it, at one end, a bulb of suitable size. A cylindrical bulb is best adapted to most work. Mercury is forced into this bulb and tube by heating the air and allowing mercury to take the place of the air expelled, as the bulb cools. The mercury is then boiled, its vapor forcing out the remaining air, and the tube is tightly sealed by melting the glass at the top. When the instrument has cooled and attained its permanent condition, it is graduated by comparison with known standards or permanent points of reference. The most convenient of such reference points are the melting point of ice and the boiling point of water. The former, on the Centigrade scale, is taken as 0° , and the latter as 100° . On the Fahrenheit

scale, the 0 is taken 32° below the freezing point of water, and the boiling point is called 212° .

Returning now to the measurement of heat, the unit most used is that quantity of heat which will raise one gramme of water from 0° to 1° C. By whatever method our measurement of heat is made, the results must be expressed in some units which involve a measurement of temperature.

If we take different bodies and heat them until the temperature has risen one degree, we shall find that the amount of heat required in each case depends upon the mass of the body and the nature of the substance. The quantity of heat required to raise the temperature of a body one degree is called the *capacity for heat* of that body. If we divide the capacity for heat of a body by its mass, we obtain as a result the quantity of heat necessary to raise a *unit mass* of the substance one degree. This is called the *specific heat* of that substance. It must, of course, be expressed in heat units, as already explained, which is the same thing as referring the substance to water as a standard.

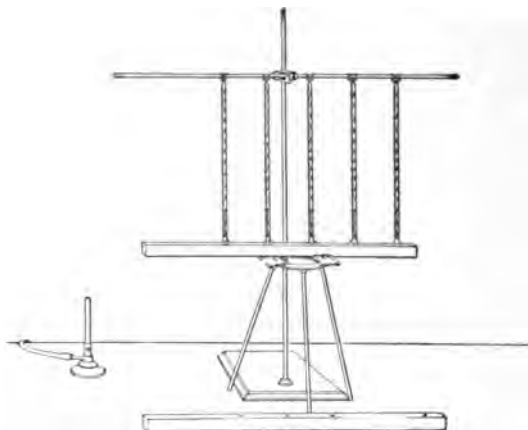
EXPERIMENT I.

Four or five students may work together on this experiment.

Apparatus.—Copper bar and iron bar, 1" section, 18" long, having 5 holes bored at intervals of three inches, beginning 1" from one end; five thermometers; Bunsen burner or alcohol lamp; pieces of asbestos felting; ring stand.

Place the copper bar on the ring, insulated from it by the asbestos, so that as little heat as possible shall be communicated to the stand. Adjust the five thermometers, each with its bulb in one of the holes in the bar, surrounded with filings of the same substance as the bar. Allow the whole apparatus to remain a few minutes until its temperature becomes uniform. Two students should then be detailed to read the thermometers at intervals of one minute,

the others taking down the readings as they are called off. Read the thermometers to one tenth of the smallest divis-



ion, by estimation. As the hand of the clock approaches the minute mark, one of the other students should notify the readers by saying "Ready ;" and as it reaches the minute mark, "Now," or "Read." The students detailed to read should then take readings of the thermometers as quickly as possible, beginning always at the same end of the bar—say at the end nearest the flame, and call off the readings distinctly enough to be heard by those noting them down. Take the first set of readings at any time before the flame is applied. They should all be the same. Then, at the beginning of a minute, by the clock, apply the flame just at the end of the bar. The flame should not be very high, and care must be taken that the thermometers have a sufficient range. After applying the flame, take readings, as directed, every minute, for five minutes. At the end of the fifth minute, remove the burner. Do not turn out the flame, however, nor change it. Continue the readings, at one minute intervals, for fifteen minutes.

Then remove the copper bar, put the iron bar in its place,

and repeat the reading, with the iron, in a similar manner. Two other students may read. You will then have two sets of readings, for copper and for iron, with an approximately identical source of heat applied for the same length of time.

Arrange the observations as follows :

Time.	THERMOMETERS.				
	A.	B.	C.	D.	E.

From these observations plot a set of curves, one for each thermometer, showing the relation between change of temperature and time. Take the same origin for each curve, and plot the curves for copper and iron on the same page, from the same origin and on the same scale. The curves may be distinguished by plotting those for iron in black, and those for copper in red.

These curves are very instructive, and will show you several things in regard to the conduction of heat, and in regard to the difference in behavior between copper and iron.

State clearly your inferences from the curves, and your reasons for them.

EXPERIMENT 2.

Two students may work together on this experiment.

Apparatus.—Two beakers or test tubes ; thermometers ; Bunsen burner.

Heat about 75 cu. cm. of water to the boiling point. Pour about 25 cu. cm. into the smaller beaker and 50 cu. cm. into the larger. Arrange the thermometers with a bulb in each beaker, the bulb in the water. Take readings of each thermometer at one minute intervals, for ten or fif-

teen minutes. Plot these results on the same page. What are your inferences as to the rate of cooling and your reasons for them?

The observations should be arranged neatly in the form of a table.

EXPERIMENT 3.

Testing Thermometers.

Apparatus.—Thermometer ; snow or ice enough to fill a litre measure when scraped fine ; wide-mouth jar ; retort stand ; Bunsen burner ; small copper beaker ; cork to fit the beaker ; glass tube about 15 mm. internal diam., 25 cm. long ; cork to fit tube ; small glass tubing.

Pound or scrape the ice as fine as possible, having first washed it. Place the pounded ice in the wide jar and fill with water nearly to the top of the ice. The temperature throughout the mass is rendered more uniform by the use of the water. Let the ice and water stand for a few minutes. Then, if more water has formed, pour some off until the ice shows white at the top. Make a hole, with a pencil or glass rod, in the centre of the mass, and insert the thermometer. The 0° mark of the scale should be just below the surface of the water, and the bulb of the thermometer must not come too near the bottom of the jar. Take care not to break the thermometer in pushing it down, for the glass of the bulb is very thin.

Read the thermometer frequently as the mercury falls, lifting it, when necessary, just enough to show the top of the column. Read to tenths of a degree. After the mercury has ceased to fall, record the lowest reading. Keep the jar of broken ice for use after making the steam reading.

Bore a hole in the large cork of such size as to hold the glass tube tightly. The tube must not be allowed to slip through. Bore two holes in the small cork. The thermometer is to be inserted in one of these holes, so that it

hangs in the middle of the tube. In the other hole insert a small bent glass tube to carry off the steam.

Having adjusted the apparatus in this way, fill the beaker about half full of water and support the whole on the retort stand. Heat the water by a rather small flame, with the thermometer in place, until it boils gently. Let it boil for some minutes, or until the mercury ceases to rise, and record the highest reading. The bulb of the thermometer must not hang so low as to be spattered by the boiling water, but the whole of the mercury column should be within the glass tube.

Remove the thermometer from the tube, and shift the cork through which it passes down very near the bulb. Allow the stem to cool to about the temperature of the room. Replace the cork in the tube, and take another steam reading with the thermometer in this position. The difference between these two steam readings shows the amount by which the column of mercury in the stem is expanded by being heated through a temperature equal to the difference between 100° and the temperature of the room. A correction for stem exposure could be calculated from these measurements, but this need not be done.

Extinguish the flame, remove the thermometer from the tube, allow it to cool in air to about 40° or 30° , and then take another reading in ice, using the same precautions as in the first case. This second ice reading will probably be lower than the first, owing to the fact that the glass of the bulb does not change so rapidly as the mercury. In careful measurements of temperature, this second, or "lag" ice reading, as it is called, is taken as the zero of the scale, and corrections are applied for stem exposure, change of zero, and inequalities in the bore of the tube. These corrections need not be found for measurements made in this course.

EXERCISE XXI.

SOUND—SONOMETER.

The sensation of sound is due to the vibration of the body which causes the sensation. If we examine a body which is producing sound, we always find that it is in a state of vibratory motion ; that is, its particles or parts are moving backward and forward with regularity. This motion is readily transferred to the surrounding substance if it is elastic, like air or most forms of matter, and is sent onward through that matter in straight lines in all directions. In fact, all action between two points not adjacent takes place by means of vibrations propagated in the medium existing between the point of origin of the disturbance and the second point. That is, the disturbance at the first point does not cause an action at the distant point without intervening mechanism, but it is propagated from one point to another in the medium as a vibration which travels in the form of waves, outward in all directions from the starting point.

In the case of the vibrations producing sound, each particle moves backward and forward in a line with the propagation of the disturbance. There will thus be produced conditions such that at some points the particles are crowded more closely together than usual and at some other points they are more widely separated than usual. The distance between the condensations is called a wave-length ; and upon the wave-length depends the pitch of the sound heard. The distance over which each particle moves back and forth is called the amplitude of the vibration, and upon

the amplitude depends the loudness of the resulting sound. The waves produced by the crowding together and drawing apart of the particles—the condensations and rarefactions of the medium—travel along with a velocity which is always the same for the same medium under the same or like conditions.

The velocity in air under ordinary conditions is about 340 metres per second ; while in liquids and elastic solids it is greater than this.

Sound may be generated in various ways. Anything which causes the displacement of particles, in an elastic medium, from the position of rest, causes sound, provided the rate of vibration is such as to be within the limits of our powers of hearing.

Different sounds may be classed as noises or as musical notes according as the effect upon the hearer is disagreeable or agreeable. The reason for a sound's producing a disagreeable or an agreeable effect is not easy to determine ; but, in general, the more regularly recurrent a disturbance is, the more nearly does the resultant sound approach to a pure musical tone, and the more agreeable it is to the hearer.

Musical sounds may be produced in several ways, depending upon

1. The vibration of strings Violin, piano
2. The vibration of rods and bars Tuning fork
3. The vibration of plates Gong
4. The vibration of membranes Drum
5. The vibration of columns of air Organ

We shall not attempt to develop, at this point, the principles governing all these, nor shall we be able to study them all experimentally. We will, however, take up the vibration of strings, as showing fundamental principles ; and make a brief experimental study of the modes of vibration and the effects upon the ear.

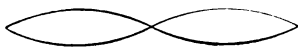
When we speak of a *string*, in acoustics, we mean a uni-

form and flexible filament of solid matter, stretched between two fixed points. We consider only the *transverse* vibrations of such a string; that is, the vibrations *across* the direction of its length. Suppose a string to be drawn aside at its centre. On letting it go it will return *past* its position of rest, and vibrate with less and less amplitude until the vibration finally dies away altogether. The result will be the propagation through the air of a corresponding vibration and the production of a musical note. We shall find, by experiment, that the greater the mass of the string, the slower the vibrations and the lower the note; the longer the string, with a given stretching force, the lower the note; and the greater the force with which it is stretched, the higher the note. In fact, we should be able to verify, by careful trial, the law expressed by the equation

$$n = \frac{1}{2l} \sqrt{\frac{F}{m}},$$

where l is the length, m the mass, per unit length, and F the tension upon the string.

If, instead of picking the string at the middle point, it be plucked at a point one quarter of its length from the end,



and a finger be held lightly on the centre, it will vibrate in two parts as shown, giving the first

overtone. The vibrations, in this case, as the length is one half what it was before, will be twice as frequent, and the pitch just one octave above that of the note given when the open string is sounded.

The points most nearly stationary, in the last case the two ends and the centre, are called *nodes*. The points of maximum motion are called *loops*, or anti-nodes.

The string may be further subdivided in a similar manner, so as to give higher overtones. It may vibrate in three, four, or five parts, or more. The ratio of the vibration frequencies to the frequency with the open string will

be as 2, 3, 4, or 5 to 1; and so on for the higher overtones.

In the actual vibration of strings, as in the violin, harp, piano, and other stringed instruments, several or all of these overtones are emitted at the same time as the fundamental; and the quality, pleasing or otherwise, depends upon the relation of these overtones to the fundamental and to each other.

EXPERIMENT.

Apparatus.—App. A; strings of metal and of gut; dynamometer; metre stick; tuning forks of known pitch; file; wire cutters.

Each string is to be prepared for use in the following way: Make, in one end, a loop about the end of the dynamometer, twisting the short end about the string. In the gut strings it will be necessary to tie a knot. Care must be taken, with all the strings, to avoid any kinks. Slip the other end of the dynamometer over the end of Apparatus A, and clamp it. Then pass the other end of the string through the hole in the piano-pin and tighten by turning the pin with the wrench. The dynamometer should hang between the clamp and the first bridge, and the string should not bind much on the bridge, in order that the dynamometer may register the true force on the string.

Tune up the string until its note coincides in pitch with that of the fork used for reference. Then note the reading of the dynamometer, and measure carefully the length between bridges. This gives F and l , in the formula already given. Measure along the string, while tight, any even length, say 50, 60, or 75 cm., mark with a file or in any other convenient way, and cut the string at these points. If more convenient, the string may be cut at the points where it passes over the bridges. In this case mark it by tapping with a hammer just over the bridge. Weigh, as carefully as you can, the length cut out. This value, divided

by the length of the portion cut, gives the mass of 1 cm. of length. If the number of vibrations of the fork is known, you have now a means of verifying the formula,

$$n = \frac{1}{2l} \sqrt{\frac{F}{m}}$$

F must be expressed in units of force corresponding to grammes and centimetres. If you have not the data for doing this, make trial of another string differing from the first in size or material. Tune to the same note as in the first case, and make the necessary measurements. It does not matter, then, in what units the force is expressed, so long as the units are the same for each string. Having the same note in each case, the number of vibrations per second must be the same, and the value of the second member of the equation, worked out for each string, must be the same. Make trial, in this way, of three strings, and test the equality by working out the value of the second member of the equation. This may not give the correct value of n , but it should be the same for each string.

Take, then, one of the strings already used and, with the movable bridge, make the length one-half what it was in the first place. Tune to the same note as before. Make the same set of observations, using the value of m already found for that string. Test the equation in the same way.

Make the record as follows :

Material of String.	n (from Fork).	l .	F .	Length Cut Out.	Weight of This Length.	m .	$\frac{1}{2l} \sqrt{\frac{F}{m}}$

Having made these measurements on the wire strings, use the gut string for the observation of the division of the string into nodes and loops, and for the production of overtones. This portion of the experiment need not be recorded.

EXERCISE XXII.

LIGHT.

In the exercise on Heat, one method of communicating heat, from one body to another at a distance, was briefly described under *radiation*. That is, heat, a form of energy, is propagated from one body to another in the form of waves, which travel in straight lines outward in all directions from the source. Light, in its passage from the luminous source to any other body, differs from radiant heat only in the length and rapidity of vibration of these waves. Both radiant heat and light, therefore, are more correctly called *radiant energy*; the names Light and Heat being applied according to the effect produced upon our senses. The eye responds to a certain limited range of wave-lengths only, the intensity of the effect depending upon the amplitude of the vibrations striking upon it.

The most convenient methods of measuring the intensity of different sources of light depend upon the fact that the illumination of any given surface is inversely proportional to the square of the distance of the surface from the source. The eye is incapable of forming an accurate judgment of the relative intensities of illumination of two portions of a surface, but can determine pretty correctly whether or not two portions of a surface are equally illuminated. If, then, we can so arrange a white screen that one part of it is lighted from one source and another adjacent part is lighted from another source, the relative intensities of the sources of light can be determined from the relation between the distances from the screen to the sources of light when the illumination of the two portions of the screen is equal.

Suppose we have an opaque body placed near a screen, and two sources of light placed at some distance from it. Then the shadow of the opaque object, from one source, will be illuminated by the light from the other source. If we then move one of the luminous sources until the two shadows appear of the same intensity, and measure the distance of each light from the screen, the intensity of the light *A* will be to that of light *B* as the square of the distance of *A* is to the square of the distance of *B* from the screen. Such an arrangement constitutes the *Rumford Photometer*. In all measurement of light the most common standard of comparison is the sperm candle of certain fixed dimensions, consuming a certain definite amount of material in a unit of time.

The *Bunsen Photometer* consists essentially of a disk of white paper having one portion made translucent by greasing or oiling. The two lights to be compared are placed on opposite sides of the screen. Then, considering one side of the screen, the grease spot is illuminated chiefly by the light which comes through from the other side, and the surrounding portion is illuminated chiefly by irregularly reflected light. One of the sources of light is moved until the illumination appears equal over the whole surface of the screen, and the distances of the sources from the screen are measured. The intensity of the light under test is then computed from these measurements.

EXPERIMENT.

Apparatus.—Card-board screen; standard candle; oil lamp; common paraffine candles; metre sticks; small wooden cylinder.

Support the card-board screen in such a way as to cut off as much of the outside light as possible. Stand the wooden cylinder about 5 cm. from the screen, so that its middle is at about the height of the flames. Arrange the standard

candle and the light under test so that the two shadows on the screen come near together at equal distances on either side of the perpendicular, through the cylinder, upon the screen.

Move one or both of the lights until the shadows appear of equal blackness. Measure the distance from each light to the shadow which it illuminates, and compute the candle power of the light from these measurements. Make three sets of observations on each light, and tabulate results as follows :

Light under Test.	Dist. of Stand- ard Candle.	Dist. of Light under Test.	Candle Power.	Mean C. P.

Test, in this way, one paraffine candle, two paraffine candles, the oil lamp, with its wick turned both edge and side toward the screen, and an incandescence electric lamp if it is available. The electric lamp should be tested in three positions: end toward the screen, filament parallel with screen, and filament perpendicular to screen.

EXERCISE XXIII.

LIGHT.—(*Continued.*)

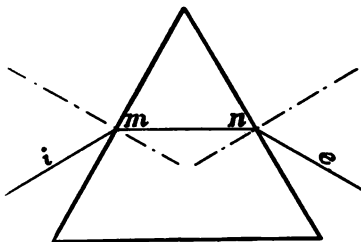
REFLECTION AND REFRACTION.

When waves of radiant energy strike upon the surface separating one medium from another, a portion is sent back into the substance in which it was first travelling, and another portion is sent on into the second substance. Let us consider, for example, the smooth surface of a glass plate, dividing the air from the glass. When a ray of light strikes this surface a portion is bent back, or *reflected*. The angle made by this reflected portion with the perpendicular let fall upon the plate at the point where the ray strikes, is equal to the angle made by the incident ray with this perpendicular; just as a billiard ball which has no twist bounds from the elastic cushion at the same angle at which it struck the cushion. That is, the angle of reflection is equal to the angle of incidence. If the under surface of the glass plate is silvered, nearly the whole of the incident light is reflected at that surface, and we have what is commonly known as a mirror. The same result is accomplished by polishing a metallic surface, such as steel or speculum metal. The latter makes the best mirror, since the reflected light does not have to pass through any portion of the second medium.

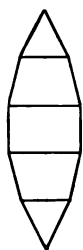
As light travels in different substances with different velocities, a ray entering a denser substance obliquely will be bent, or *refracted*, toward the perpendicular let fall upon the surface of separation. The ratio of the velocities in the two substances separated by the surface in question is

a measure of the amount of refraction, and is called the *index of refraction*.

Let us consider the action in the case of a piece of glass of triangular section—called a *prism*. Suppose the incident ray, i , enters obliquely, as shown. It is bent, in the prism, toward the normal through m , and the emergent ray, e , is bent away from the normal through n . The change in direction is the same, whether i or e is the incident ray.



If we take portions of a number of prisms, of different angles, and put them together, as in the figure, the rays passing through the portions near the edges are deviated to a greater extent than those passing through the central portion. A transparent body, therefore, which has one or both of its surfaces uniformly curved—a *lens*—may be looked upon as made up of a very great number of prisms; and if the surface of the lens is properly shaped, all the rays from a point on one side of the lens will meet at some point on the other side of the lens.



A lens of this sort, which is thicker in the middle than at the edges, is called a *converging lens*. The point from which the rays start and that at which they meet are called *conjugate foci*. If the incident rays are parallel, the point at which the emergent rays meet is called the *principal focus*.

EXPERIMENT I.

Reflection.

Apparatus.—2 pieces of plane mirror; 3 sheets of white paper about 50 cm. square; candle; metre stick; four large cork stoppers.

1. Support the pieces of mirror with their planes vertical by sticking them into cuts in the corks. Place the paper flat upon the table, and rule a straight line across its centre. Stand one of the mirrors along this line, and the candle at some convenient distance in front of it, on the paper. Mark the point under the centre of the candle. Make a mark at some other point from which the reflection of the candle-flame can be seen, and, placing the eye over that point, draw a line along the paper by means of the metre stick, toward the image of the tip of the flame. Proceed similarly from some other point from which the reflection of the flame is visible.

Remove the mirror and candle. Draw a perpendicular across the central line, from the point marking the position of the candle, and produce all the other lines until they meet the perpendicular. Make any necessary measurements, and state your conclusions as to the relation between the position of the object and the position of the image.

2. Take a fresh sheet of paper, and rule across it, centrally, two lines making right angles with each other. Place one mirror upon each line, facing the same corner, and place the candle in front of them. Proceed as before, drawing lines from the point of sight toward each image that can be seen, and complete the construction as in the first case. What new facts, if any, does this experiment show?

3. Upon the third sheet of paper, draw two parallel lines near its centre and about 10 cm. apart. Place the mirrors over these lines, facing each other, and the candle just beyond them about midway between the lines. A great number of images will be seen stretching away in either direction. Draw lines, from some point about opposite the candle, to the first two on each side, and complete the construction as in the former cases. Show the path of the ray of light making the second image, from the candle to the eye.

EXPERIMENT 2.

Refraction.

Apparatus.—Small converging lens ; metre stick ; 2 pieces of card-board ; corks ; candle.

Support the lens and one of the pieces of card-board by sticking each into a slit in a cork. Place the candle, lens, and card in line upon the table, the lens in the middle, so that the image of the candle-flame is received upon the card. The image will be inverted. Move the card and the lens, if necessary, until the image is as distinct as you can make it. Call the distance of the candle from the lens p , and the distance of the screen from the lens p' . Then p and p' are conjugate foci. Measure and record these distances. Change the distance of the candle from the lens, and, moving the card only, find the point at which the image is most distinct. Make three trials, with different values for p and p' .

Cut or punch, in the second card, a small hole about 3 mm. in diameter, and hold near to the centre of the lens. What is the effect on the image?

Place the screen upon the table, and move the lens, in front of it, until a distinct image is obtained of some distant object, several hundred feet away. Measure the distance from the lens to the screen. The rays from the distant object may be regarded as parallel, and the distance from the lens to the image is therefore the principal focal distance. Call this f .

Then, using for f the mean of several measurements, see if the previously found values for p and p' will satisfy the formula

$$\frac{1}{p} + \frac{1}{p'} = \frac{1}{f}.$$

Make a separate computation for each pair of values of p and p' .

Observations should be recorded in the following form :

ϕ .	ϕ' .	$\int$ computed.	$\int$ by experiment.

EXERCISE XXIV.

MAGNETISM.

Any body which attracts iron is said to possess magnetic properties, and is called a *magnet*. This property can be communicated by contact or proximity ; so that a piece of iron suspended from either pole of a magnet will itself possess magnetic properties, and will attract other pieces of iron. We find that this magnetic force is exerted through the medium surrounding the magnet, whatever be the nature of this medium ; and when the conditions are constant, the direction and the magnitude of this force have each a definite value at each point.

In magnets of the open form, that is, those which have ends, the magnetic force is most apparent about certain regions which are called the *poles*. The normal magnet has two such poles, whose properties are opposite in character. The pole pointing toward the north is called the *north pole*—sometimes the *marked* pole—and the pole pointing toward the south, the *south pole*, or the unmarked pole.

If we could separate a north pole from a south pole, and place this north pole, free from other disturbances, within the range of the attraction of a magnet, we should find that it would move in a certain direction. This is called the direction of the magnetic force ; and the north pole would be found to move around in a closed path, passing through the substance of the magnet, from one pole to another—from the south pole to the north pole—and around through the

surrounding medium to the first pole again. A south pole would move in a direction opposite to that taken by the north pole. The region of space, about the magnet, in which the magnetic force is apparent, is called the *magnetic field*. Although the magnetic field is strongest near the poles of a magnet, we should find, if it were possible to explore by means of a single pole, that the magnetic force is strongest within the body of the magnet. If the magnet is closed upon itself, in the form of a ring, the magnetic field about it is very weak, all the force, or nearly all, passing in a circuit through the body of the magnet.

A field of magnetic force can be conveniently represented by means of lines, whose direction is the direction of the force. The strength of the force is represented, conventionally, by the closeness together of these lines; so that the strength of a field, through any surface, is expressed by the number of lines passing through a unit area of that surface.

A magnet, if free to move and suspended in a magnetic field, will place itself with its axis parallel to the resultant direction of the magnetic force. If perfectly free to move, it will place itself in such a position that the direction of the force due to its magnetism will coincide with the direction of the force in the original field. "The magnetic actions which take place in the field, and which are due to the conditions of strain in the medium, are well illustrated by supposing, with Faraday, that each line of force, like a stretched elastic thread, is endowed with a tendency to shorten along its length; while at the same time these lines of force are self-repellent. So that as a result there is a tension developed in the medium along these lines and a pressure at right angles to them." [Barker.]

The magnetic force tends always to take the easiest path. Any piece of iron introduced into a magnetic field will therefore cause a change in the direction of the force at and about that point.

The field in the vicinity of a magnet may be conveniently studied in two ways. A small piece of iron wire, suspended from its middle by a silk fibre, when moved about near a magnet, will take the direction of the magnetic force at each point, while its effect upon the field is insignificant. Another method is by the use of iron filings, which when dusted over a glass plate or piece of paper, held near a magnet, and tapped lightly, arrange themselves in curves which show very clearly the direction of the force. The figures thus produced were called by Dr. Gilbert, who first used this method, *magnetic phantoms*.

EXPERIMENT.

Apparatus.—Bar magnets; iron filings; soft iron wire; silk fibre; paper or glass plate; iron washer; needles; cork; dish of water.

1. In using the iron filings, the magnets must be placed or held firmly so that they will not move during the manipulation. The filings should be scattered evenly and thinly over the plate resting upon the magnets, and made to arrange themselves by tapping the plate *lightly* with a pencil or small piece of wood. If the plate or paper is then lifted with care vertically out of the field, the arrangement of the filings will not be disturbed.

Study, by means of the filings, the field about

1st, A single pole, magnet upright,

2d, A complete magnet,

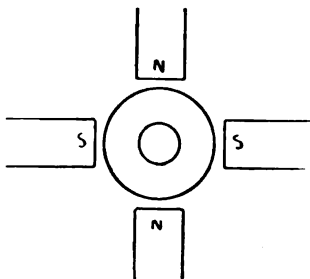
3d, Two like poles, near together,

4th, Two unlike poles, near together,

5th, Four poles, arranged as in the figure,



6th, Four poles, as in the 5th, with an iron ring in the centre. An iron washer will answer.



In each case, after obtaining the figure, and before removing the filings, investigate the field above the paper or plate, by means of a short piece of iron wire, say one or two centimetres long, suspended by the silk fibre, as described.

Draw in your note-book the figure given by the filings in each case, and describe so far as you can the field above the paper, as shown by the suspended short piece of wire.

2. Take a number of short pieces of steel wire—small needles will do very well—and magnetize them by stroking on the end of a permanent magnet. Each should be given the same number of strokes, and all should be magnetized alike; that is, in each one the eye of the needle should be north. Stick them through small pieces of cork, so that each needle projects much less on one side than on the other, and so that the short ends are like poles. Then float them in a vessel of water. If thoroughly wetted, they will float upright. Take care that they do not stick together in groups.

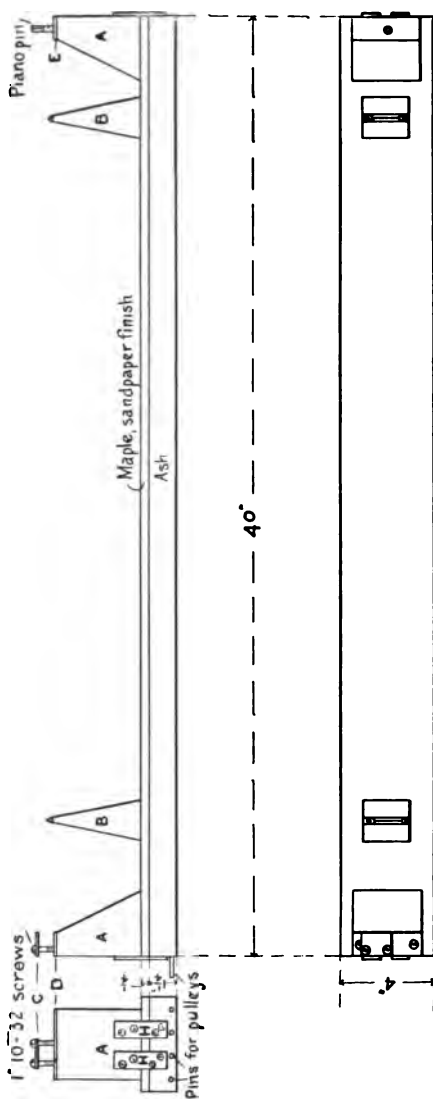
Then approach to them, from above, a permanent magnet held vertically, its lower pole being unlike the upper poles of the floating magnets. The floating magnets are then under the action of two sets of forces. They are all attracted by the upper magnet, and all repelled by each other. The figures in which they arrange themselves are interesting and instructive. Try different numbers of the floating magnets at a time; that is, first two, then three, four, five, and so on. Study the figures which are formed, and the action of the forces. Draw the figures in your note-book.

APPENDIX.

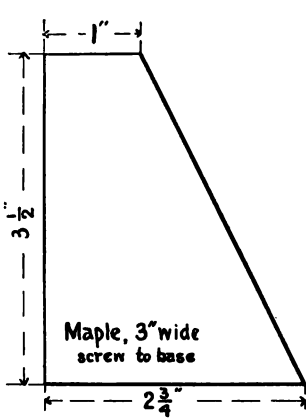
APPARATUS.

THE most important piece of apparatus used is that which, for brevity and for want of a better name, is called "Apparatus A." It is shown in detail in the drawing. It will be necessary to have, of this piece, only as many as there are students in a section. If wood and metal shops are connected with the school, each student could, to advantage, make the apparatus he is to use, in the course of his shop work during the year, before beginning this course.

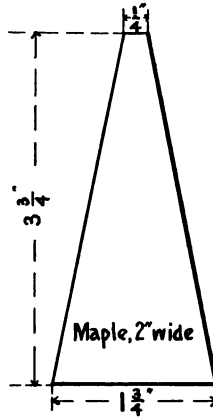
There are several of the pieces named in the list below which it will not be necessary to duplicate for each student of the section. The balances, for instance, are not in constant use, and eight balances will be found ample for a section of twelve. Each balance should be assigned to certain students, for use, and they should be held responsible for loss of weights or damage to the balance. It is not best to attempt to work with a poor or inaccurate balance. A very good one can be imported, free of duty, for about \$8, or less, and suitable weights, up to 100 grammes, for about \$2. This balance is sensitive to one milligramme, if kept in good condition, but the weights are not accurate to that extent, and may need adjustment. Working with a poor balance and inaccurate weights, the student becomes careless and accustomed to treat a balance roughly, which is a habit to be avoided. He should not be allowed to handle the weights, except with the forceps, nor to leave the balance uncovered.



APPARATUS A.



Block A



Bridge B

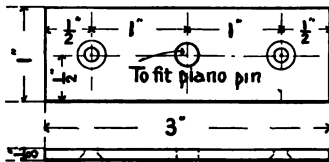
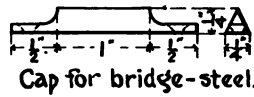


Plate E-steel.



Cap for bridge-steel.

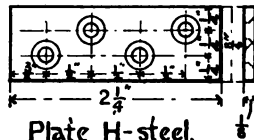


Plate H-steel.

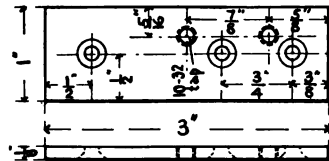


Plate D-steel

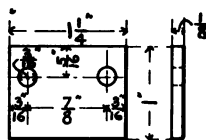
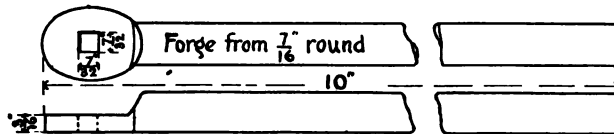


Plate C-steel



Wrench - iron.

The dynamometer used with Apparatus A may be of any convenient pattern, reading up to 50 kilogrammes. An ordinary spring balance is bulky and inconvenient to use. A good spring dynamometer can be constructed in the shops of the school or by the makers of Apparatus A. Probably not more than five will be in use at any one time, with a section of twelve.

The brass blanks for the heavy weights may conveniently be cut from a one-inch brass rod, and each should be furnished with a wire bail, or may be supported by a cord passing through a hole bored near one end. The wire bail is the more convenient and should be deep enough to hang on the 16 mm. rod without binding. These weights may, of course, be made up from sheet lead, by the students; but in this form they are less permanently useful.

The pulleys to be used with Apparatus A should be nearly, if not quite, 2 inches in diameter, and must run with as little friction as possible. They should be arranged to hook upon the pins at the end of the board.

The iron and copper bars used in Exercise XX. are 1 inch in section and 18 inches long. Five $\frac{3}{8}$ inch holes, $\frac{7}{8}$ inch deep, for the bulbs of the thermometers, are bored 3 inches apart, beginning 1 inch from one end. The flame is applied at the other end.

It is assumed that the laboratory is equipped with a clock ticking seconds. Such a clock can be procured for a moderate sum, and will be found a very useful piece of furniture. It is convenient to have upon it a long seconds-hand and a large dial, with sufficiently heavy division marks to be seen from any part of the room. It is not necessary that the clock should mark the minutes, but it should be so arranged, with electrical contacts, that a sounder in connection with it will sound the seconds when desired.

The first list below gives the pieces of apparatus which may be used generally by any student requiring them. The pieces named in the second list should be issued to each

student, charged to him, and kept by him in his locker, according to the system adopted in most chemical laboratories. The student is credited with the apparatus returned in good condition at the end of the course.

APPARATUS—GENERAL LIST.

Apparatus A. (See DRAWING.)

Dynamometer.

Pulleys.

Metre stick.

Wire, Copper, No. 18, hard drawn, 0.040 inch diameter.

Copper, No. 18, soft drawn.

Iron, soft, two sizes.

Steel, piano wire, two sizes.

Brass, spring, two sizes, same as steel.

Brass, soft, two sizes, same as steel.

Balance and weights.

Stand for supporting pendulums.

Burette 50 c.c. (4 or 5 will be sufficient for the section).

Retort stand, with clamps and rings.

Barometer tube.

Crystallizing dish.

Mercury.

Copper bar.)
Iron bar.) (Three of each will do for a section of twelve.)

Bunsen burner and rubber tubing.

Tuning forks.

Bar magnets.

Distilled water.

Liquids for specific gravity determinations.

Tall jar (hydrometer jar).

Small plane mirrors.

Small converging lens.

Oil lamp.

INDIVIDUAL LIST.

3-cornered file.

Wire cutters.

Graduate cylinder, 25 c.c.

3 metal cylinders, steel, brass, copper.

(These should be of different sizes, not more than $\frac{3}{8}$ inch diameter, 1 inch long, cut from rolled rods and the ends squared.)

3 brass blanks for weights, 50 gm., 100 gm., 200 gm.

Cord (small braided fish line).

	4 × 16 mm.	} section.
3 deal rods, even grain, 80 cm. long,	8 × 16 mm.	
	8 × 8 mm.	

Card-board, 2 sheets.

White paper, 3 sheets 50 cm. square.

Wooden blocks (Prang's models), cone, pyramid, prism, cylinder, sphere, hemisphere, cube.

Wire gauge.

1 short wooden rod, 5 cm. long.

2 wooden rods, 20 cm. long.

Glass plate, about 4 × 6 inches.

2 pendulum bobs, different sizes.

Thistle tube.

Long glass tube.

25 cm. rubber tubing.

Thin sheet rubber, 5 cm. square.

Wooden disk (to cover thistle tube).

Thermometer, 200° C.

Specific gravity bottle.

Sulphur, lead, etc., for sp. gr.

Thread.

Tumbler.

Test tube.

Glass tube, 8 mm. diameter, 2 pieces, 75 cm. long and 50 cm. long.

Funnel tube, long stem.

Specimen tube, about $4 \times \frac{3}{4}$ inches.

Asbestos felting, 2 strips about 3×1 inch each.

2 beakers, 50 c.c. and 25 c.c.

Gut string (violin D).

Iron filings.

Silk fibre.

Iron washer, $\frac{1}{4}$ inch thick.

12 small needles.

Corks.

Rubber stoppers.

Standard candle.

2 paraffine candles.

SOUND, LIGHT, AND HEAT.

By **MARK R. WRIGHT**, author of "Elementary Physics." With 162 Illustrations and Diagrams. 12mo. 272 pages. 80 cents.

This volume is an elementary text-book on Sound, Light, and Heat, treated experimentally. It is essential that the experiments should be performed. The numerical results which illustrate the text should not take the place of measurements made by the student. The experiments demand no expensive apparatus; the aim has been to avoid elaborate instruments; descriptions of the apparatus used appear in the book or in the appendix. Examples are given frequently throughout the work.

HEAT.

A Manual for Students in Advanced Classes.

By **MARK R. WRIGHT**. With numerous Illustrations and Diagrams. Crown 8vo. \$1.50.

"A well-planned and well-executed work. . . . The book is in physics what Remsen's text-book is in chemistry, a well-prepared outline of the theory and experimental method of exposition of the science."—*Science*, N. Y.

PHYSICAL OPTICS.

By **R. T. GLAZEBROOK, M.A., F.R.S.**, Fellow and Lecturer of Trinity College; Demonstrator of Physics at the Cavendish Laboratory, Cambridge. With 183 Woodcuts of Apparatus, etc. (TEXT-BOOKS OF SCIENCE.) 12mo. 448 pages. \$2.00.

Contents.—Wave Motion, The Rectilinear Propagation of Waves, Reflection and Refraction, Prisms and Lenses, Interference, Colors of Thin Plates, Diffraction, Dispersion and Achromatism, Spectrum Analysis, Absorption and Anomalous Dispersion, Double Refraction, Refraction and Reflection of Polarized Light, Interference of Polarized Light, Circular Polarization, Electro-Optics, The Velocity of Light, etc., etc.

THEORY OF HEAT.

By **J. CLERK MAXWELL, M.A.**, etc., etc. Tenth Edition, with Corrections and Additions by **LORD RAYLEIGH**, Sec. R. S. (TEXT-BOOKS OF SCIENCE.) 12mo. 357 pages. \$1.50.

The aim of this book is to exhibit the scientific connection of the various steps by which our knowledge of the Phenomena of Heat has been extended. It treats of Thermometry, Calorimetry, Lines of Equal Temperature on the Indicator Diagram, Adiabatic Lines, Heat Engines, Latent Heat, Thermodynamics of Gases, Free Expansion, Determination of Heights by the Barometer, Radiation, Convection Currents, Diffusion of Heat by Conduction, Diffusion of Fluids, Capillarity, Elasticity and Viscosity, Molecular Theory of the Constitution of Bodies, etc., etc.

* * For other books on the subjects of *Sound, Light, and Heat*, see *Longmans, Green, & Co.'s Educational Catalogue*.

LONGMANS, GREEN, & CO. 15 East Sixteenth Street, New York.

ELEMENTARY PHYSICS.

By MARK R. WRIGHT, author of "Sound, Light, and Heat." With 238 Illustrations. 12mo. 256 pages. 80 cents.

This work will serve as a suitable text-book for any class beginning the study of physics. The leading facts are brought under the notice of the student by easy experiments that do not demand expensive apparatus. Full instructions are given for the construction of the apparatus, in the text, or in the appendix. The author believes that in early lessons it is inadvisable to trouble the student either with theories or with the generalizations that prove such a valuable aid to the advanced student.

BOWDOIN COLLEGE.

"I consider it very well adapted to beginners in the science. The long list of experiments affords ample material from which a course of any length may be adapted. The whole trend of the book is in the right direction—the teaching of physics by experiment."—C. C. HUTCHINS, Brunswick, Me.

"It should take high rank, and come into wide use among our schools."—*Education*, Boston.

"This book possesses considerable merit. The matter contained in it is just about as much as would cover the course usually taken in a year's school work; the explanatory text is couched in the clearest language, and the experiments described are capable of being easily brought to a successful termination. . . . The book compares most favorably with any written for the purpose of imparting a rudimentary knowledge of magnetic and electrical phenomena."—*Nature*.

"The treatment is simple and clear, and the experiments given are admirably chosen; by their aid the subject is logically developed, and they are such as can be performed with very simple apparatus. . . . Altogether, this is one of the best primary books on physics that we have seen."—*Critic*, New York.

PRACTICAL PHYSICS.

By R. T. GLAZEBROOK, M.A., F.R.S., and W. N. SHAW, M.A., Demonstrators at the Cavendish Laboratory, Cambridge. With Woodcuts. (TEXT-BOOKS OF SCIENCE.) Fourth Edition. Revised and Enlarged. Crown 8vo. 260 pages. \$2.50.

This book is intended for the Assistance of Teachers and Students in Physical Laboratories. It contains chapters on Physical Measurements, Units of Measurements, Physical Arithmetic, Measurement of the more Simple Quantities, Measurement of Mass and Determination of Specific Gravities, Mechanics of Solids, Liquids, and Gases, Acoustics, Thermometry, and Expansion. Calorimetry, Tension of Vapor and Hygrometry, Photometry, Mirrors and Lenses, Spectra, Refractive Indices and Wave-Lengths, Polarized Light, Color Vision, Magnetism, Electricity, Experiments in the Fundamental Properties of Electric Currents, Ohm's Law, Galvanometric Measurement of a Quantity of Electricity, etc., etc.

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

SOUND, LIGHT, AND HEAT.

By MARK R. WAGNET, author of "Elementary Physics." With
 Uniform and Diagrams. 12mo. 272 pages. 50 cents.

This volume is an elementary text-book on Sound, Light, and Heat
 experimentally. It is essential that the experiments should be
 the numerical results which illustrate the text should not take the
 apparatus; the apparatus used appear in the book or in the appendix.
 given frequently throughout the work.

HEAT.

A Manual for Students in Advanced Classes.

By MARK R. WAGNET. With numerous Illustrations and Diagrams.
 8vo. \$1.50.

"A well-planned and well-illustrated work. The book
 what Remsen's text-book is in chemistry, a well-prepared outline
 and experimental method of exposition of the science."—*Science*

PHYSICAL OPTICS.

By R. T. GLAZEBROOK, M.A., F.R.S., Fellow and Lecturer
 College; Demonstrator of Physics at the Cavendish
 bridge. With 183 Woodcuts of Apparatus, etc. (SCIENCE.) 12mo. 448 pages. \$2.00.

Contents.—Wave Motion, The Rectilinear Propagation of
 and Refraction, Prisms and Lenses, Interference, Colors of
 fraction, Dispersion and Achromatism, Spectrum Analysis,
 Anomalous Dispersion, Double Refraction, Refraction and
 ized Light, Interference of Polarized Light, Circular Po-
 Optics, The Velocity of Light, etc., etc.

THEORY OF HEAT.

By J. CLERK MAXWELL, M.A., etc., etc. Tenth Edition
 and Additions by LORD RAYLEIGH, Sec. R. S.
 SCIENCE.) 12mo. 357 pages. \$1.50.

The aim of this book is to exhibit the scientific con-
 steps by which our knowledge of the Phenomena of Heat
 It treats of Thermometry, Calorimetry, Lines of Equi-
 indicator Diagram, Adiabatic Lines, Heat Engines, Dy-
 namics of Gases, Free Expansion, Determination of
 heat, Radiation, Convection Currents, Diffusion of
 Diffusion of Fluids, Capillarity, Elasticity and Viscosity,
 the Constitution of Bodies, etc., etc.

"For other books on the subjects of Sound, Light,
 Grav., & Co.'s Educational Catalogue."

LONGMANS, GREEN, & CO., 15 East Sixth

ELEMENTARY PHYSICS

By MARK R. WHEAT, author of "Heat,"
Illustrations, 32mo., 225 pages.

This work will serve as a satisfactory study of physics. The leading facts are illustrated by easy experiments that do not need elaborate apparatus. Instructions are given for the construction of the apparatus in an appendix. The author believes that a study of the student either with theories or with the experiments is a valuable aid to the advancement of science.

"I consider it very well adapted to the needs of experiments efforts simple nature that can be adapted. The whole trend of the book is toward physics by experiment."—C. C. BURTON.

"It should take high rank and come in the hands of every student of physics."
Education, Boston.

"This book possesses considerable merit. It is just about as much as would cover the course in physics; the explanatory text is excellent in the experiments described are capable of being made in the laboratory. . . . The book compares well with the purpose of imparting a rudimentary knowledge of phenomena."—*Nature*.

"The treatment is simple and clear, and the material is well chosen; by their aid the subject is highly accessible as can be performed with very simple apparatus. . . . one of the best primary books on physics that we have."—*York*.

PRACTICAL PHYSICS

By R. T. GLAZEBROOK, M.A., F.R.S., and W. E. GLAZEBROOK, M.A.,
F.R.S., of the Cavendish Laboratory, Cambridge.
(TEXT-BOOKS OF SCIENCE.) Fourth Edition.
Crown 8vo., 260 pages. \$2.50.

This book is intended for the Assistance of Teachers in Physical Laboratories. It contains chapters on Physical Measurements, Physical Arithmetic, Measurement of Length, Mass, Time, Temperature, Density, Specific Gravity, Viscosity, Surface Tension, Elasticity, Solids, Liquids, and Gases, Acoustics, Thermodynamics, Heat, Calorimetry, Expansion, Contraction, Diffusion, Osmosis, Spectra, Refractive Indices and Wave Lengths, Polarization, Magnetism, Electricity, Measurements in the Laboratory, Currents, Ohm's Law, Resistance, Inductance, Capacitance, etc., etc.

SOUND, LIGHT, AND HEAT.

By MARK R. WRIGHT, author of "Elementary Physics." With 162 Illustrations and Diagrams. 12mo. 272 pages. 80 cents.

This volume is an elementary text-book on Sound, Light, and Heat, treated experimentally. It is essential that the experiments should be performed. The numerical results which illustrate the text should not take the place of measurements made by the student. The experiments demand no expensive apparatus; the aim has been to avoid elaborate instruments; descriptions of the apparatus used appear in the book or in the appendix. Examples are given frequently throughout the work.

HEAT.

A Manual for Students in Advanced Classes.

By MARK R. WRIGHT. With numerous Illustrations and Diagrams. Crown 8vo. \$1.50.

"A well-planned and well-executed work. . . . The book is in physics what Remsen's text-book is in chemistry, a well-prepared outline of the theory and experimental method of exposition of the science."—*Science*, N. Y.

PHYSICAL OPTICS.

By R. T. GLAZEBROOK, M.A., F.R.S., Fellow and Lecturer of Trinity College; Demonstrator of Physics at the Cavendish Laboratory, Cambridge. With 183 Woodcuts of Apparatus, etc. (TEXT-BOOKS OF SCIENCE.) 12mo. 448 pages. \$2.00.

Contents.—Wave Motion, The Rectilinear Propagation of Waves, Reflection and Refraction, Prisms and Lenses, Interference, Colors of Thin Plates, Diffraction, Dispersion and Achromatism, Spectrum Analysis, Absorption and Anomalous Dispersion, Double Refraction, Refraction and Reflection of Polarized Light, Interference of Polarized Light, Circular Polarization, Electro-Optics, The Velocity of Light, etc., etc.

THEORY OF HEAT.

By J. CLERK MAXWELL, M.A., etc., etc. Tenth Edition, with Corrections and Additions by LORD RAYLEIGH, Sec. R. S. (TEXT-BOOKS OF SCIENCE.) 12mo. 357 pages. \$1.50.

The aim of this book is to exhibit the scientific connection of the various steps by which our knowledge of the Phenomena of Heat has been extended. It treats of Thermometry, Calorimetry, Lines of Equal Temperature on the Indicator Diagram, Adiabatic Lines, Heat Engines, Latent Heat, Thermodynamics of Gases, Free Expansion, Determination of Heights by the Barometer, Radiation, Convection Currents, Diffusion of Heat by Conduction, Diffusion of Fluids, Capillarity, Elasticity and Viscosity, Molecular Theory of the Constitution of Bodies, etc., etc.

*** For other books on the subjects of Sound, Light, and Heat, see Longmans, Green, & Co.'s Educational Catalogue.*

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

ELEMENTARY PHYSICS.

By MARK R. WRIGHT, author of "Sound, Light, and Heat." With 238 Illustrations. 12mo. 256 pages. 80 cents.

This work will serve as a suitable text-book for any class beginning the study of physics. The leading facts are brought under the notice of the student by easy experiments that do not demand expensive apparatus. Full instructions are given for the construction of the apparatus, in the text, or in the appendix. The author believes that in early lessons it is inadvisable to trouble the student either with theories or with the generalizations that prove such a valuable aid to the advanced student.

BOWDOIN COLLEGE.

"I consider it very well adapted to beginners in the science. The long list of experiments affords ample material from which a course of any length may be adapted. The whole trend of the book is in the right direction—the teaching of physics by experiment."—C. C. HUTCHINS, Brunswick, Me.

"It should take high rank, and come into wide use among our schools."—*Education*, Boston.

"This book possesses considerable merit. The matter contained in it is just about as much as would cover the course usually taken in a year's school work; the explanatory text is couched in the clearest language, and the experiments described are capable of being easily brought to a successful termination. . . . The book compares most favorably with any written for the purpose of imparting a rudimentary knowledge of magnetic and electrical phenomena."—*Nature*.

"The treatment is simple and clear, and the experiments given are admirably chosen; by their aid the subject is logically developed, and they are such as can be performed with very simple apparatus. . . . Altogether, this is one of the best primary books on physics that we have seen."—*Critic*, New York.

PRACTICAL PHYSICS.

By R. T. GLAZEBROOK, M.A., F.R.S., and W. N. SHAW, M.A., Demonstrators at the Cavendish Laboratory, Cambridge. With Woodcuts. (TEXT-BOOKS OF SCIENCE.) Fourth Edition. Revised and Enlarged. Crown 8vo. 260 pages. \$2.50.

This book is intended for the Assistance of Teachers and Students in Physical Laboratories. It contains chapters on Physical Measurements, Units of Measurements, Physical Arithmetic, Measurement of the more Simple Quantities, Measurement of Mass and Determination of Specific Gravities, Mechanics of Solids, Liquids, and Gases, Acoustics, Thermometry, and Expansion. Calorimetry, Tension of Vapor and Hygrometry, Photometry, Mirrors and Lenses, Spectra, Refractive Indices and Wave-Lengths, Polarized Light, Color Vision, Magnetism, Electricity, Experiments in the Fundamental Properties of Electric Currents, Ohm's Law, Galvanometric Measurement of a Quantity of Electricity, etc., etc.

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

SOUND, LIGHT, AND HEAT.

By MARK R. WRIGHT, author of "Elementary Physics." With 162 Illustrations and Diagrams. 12mo. 272 pages. 80 cents.

This volume is an elementary text-book on Sound, Light, and Heat, treated experimentally. It is essential that the experiments should be performed. The numerical results which illustrate the text should not take the place of measurements made by the student. The experiments demand no expensive apparatus; the aim has been to avoid elaborate instruments; descriptions of the apparatus used appear in the book or in the appendix. Examples are given frequently throughout the work.

HEAT.

A Manual for Students in Advanced Classes.

By MARK R. WRIGHT. With numerous Illustrations and Diagrams. Crown 8vo. \$1.50.

"A well-planned and well-executed work. . . . The book is in physics what Remsen's text-book is in chemistry, a well-prepared outline of the theory and experimental method of exposition of the science."—*Science*, N. Y.

PHYSICAL OPTICS.

By R. T. GLAZEBROOK, M.A., F.R.S., Fellow and Lecturer of Trinity College; Demonstrator of Physics at the Cavendish Laboratory, Cambridge. With 183 Woodcuts of Apparatus, etc. (TEXT-BOOKS OF SCIENCE.) 12mo. 448 pages. \$2.00.

Contents.—Wave Motion, The Rectilinear Propagation of Waves, Reflection and Refraction, Prisms and Lenses, Interference, Colors of Thin Plates, Diffraction, Dispersion and Achromatism, Spectrum Analysis, Absorption and Anomalous Dispersion, Double Refraction, Refraction and Reflection of Polarized Light, Interference of Polarized Light, Circular Polarization, Electro-Optics, The Velocity of Light, etc., etc.

THEORY OF HEAT.

By J. CLERK MAXWELL, M.A., etc., etc. Tenth Edition, with Corrections and Additions by LORD RAYLEIGH, Sec. R. S. (TEXT-BOOKS OF SCIENCE.) 12mo. 357 pages. \$1.50.

The aim of this book is to exhibit the scientific connection of the various steps by which our knowledge of the Phenomena of Heat has been extended. It treats of Thermometry, Calorimetry, Lines of Equal Temperature on the Indicator Diagram, Adiabatic Lines, Heat Engines, Latent Heat, Thermodynamics of Gases, Free Expansion, Determination of Heights by the Barometer, Radiation, Convection Currents, Diffusion of Heat by Conduction, Diffusion of Fluids, Capillarity, Elasticity and Viscosity, Molecular Theory of the Constitution of Bodies, etc., etc.

* * For other books on the subjects of Sound, Light, and Heat, see Longmans, Green, & Co.'s Educational Catalogue.

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

ELEMENTARY PHYSICS.

By MARK R. WRIGHT, author of "Sound, Light, and Heat." With 238 Illustrations. 12mo. 256 pages. 80 cents.

This work will serve as a suitable text-book for any class beginning the study of physics. The leading facts are brought under the notice of the student by easy experiments that do not demand expensive apparatus. Full instructions are given for the construction of the apparatus, in the text, or in the appendix. The author believes that in early lessons it is inadvisable to trouble the student either with theories or with the generalizations that prove such a valuable aid to the advanced student.

BOWDOIN COLLEGE.

"I consider it very well adapted to beginners in the science. The long list of experiments affords ample material from which a course of any length may be adapted. The whole trend of the book is in the right direction—the teaching of physics by experiment."—C. C. HUTCHINS, Brunswick, Me.

"It should take high rank, and come into wide use among our schools."—*Education*, Boston.

"This book possesses considerable merit. The matter contained in it is just about as much as would cover the course usually taken in a year's school work; the explanatory text is couched in the clearest language, and the experiments described are capable of being easily brought to a successful termination. . . . The book compares most favorably with any written for the purpose of imparting a rudimentary knowledge of magnetic and electrical phenomena."—*Nature*.

"The treatment is simple and clear, and the experiments given are admirably chosen; by their aid the subject is logically developed, and they are such as can be performed with very simple apparatus. . . . Altogether, this is one of the best primary books on physics that we have seen."—*Critic*, New York.

PRACTICAL PHYSICS.

By R. T. GLAZEBROOK, M.A., F.R.S., and W. N. SHAW, M.A., Demonstrators at the Cavendish Laboratory, Cambridge. With Woodcuts. (TEXT-BOOKS OF SCIENCE.) Fourth Edition. Revised and Enlarged. Crown 8vo. 260 pages. \$2.50.

This book is intended for the Assistance of Teachers and Students in Physical Laboratories. It contains chapters on Physical Measurements, Units of Measurements, Physical Arithmetic, Measurement of the more Simple Quantities, Measurement of Mass and Determination of Specific Gravities, Mechanics of Solids, Liquids, and Gases, Acoustics, Thermometry, and Expansion. Calorimetry, Tension of Vapor and Hygrometry, Photometry, Mirrors and Lenses, Spectra, Refractive Indices and Wave-Lengths, Polarized Light, Color Vision, Magnetism, Electricity, Experiments in the Fundamental Properties of Electric Currents, Ohm's Law, Galvanometric Measurement of a Quantity of Electricity, etc., etc.

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

SOUND, LIGHT, AND HEAT.

By MARK R. WRIGHT, author of "Elementary Physics." With 162 Illustrations and Diagrams. 12mo. 272 pages. 80 cents.

This volume is an elementary text-book on Sound, Light, and Heat, treated experimentally. It is essential that the experiments should be performed. The numerical results which illustrate the text should not take the place of measurements made by the student. The experiments demand no expensive apparatus; the aim has been to avoid elaborate instruments; descriptions of the apparatus used appear in the book or in the appendix. Examples are given frequently throughout the work.

HEAT.

A Manual for Students in Advanced Classes.

By MARK R. WRIGHT. With numerous Illustrations and Diagrams. Crown 8vo. \$1.50.

"A well-planned and well-executed work. . . . The book is in physics what Remsen's text-book is in chemistry, a well-prepared outline of the theory and experimental method of exposition of the science."—*Science*, N. Y.

PHYSICAL OPTICS.

By R. T. GLAZEBROOK, M.A., F.R.S., Fellow and Lecturer of Trinity College; Demonstrator of Physics at the Cavendish Laboratory, Cambridge. With 183 Woodcuts of Apparatus, etc. (TEXT-BOOKS OF SCIENCE.) 12mo. 448 pages. \$2.00.

Contents.—Wave Motion, The Rectilinear Propagation of Waves, Reflection and Refraction, Prisms and Lenses, Interference, Colors of Thin Plates, Diffraction, Dispersion and Achromatism, Spectrum Analysis, Absorption and Anomalous Dispersion, Double Refraction, Refraction and Reflection of Polarized Light, Interference of Polarized Light, Circular Polarization, Electro-Optics, The Velocity of Light, etc., etc.

THEORY OF HEAT.

By J. CLERK MAXWELL, M.A., etc., etc. Tenth Edition, with Corrections and Additions by LORD RAYLEIGH, Sec. R. S. (TEXT-BOOKS OF SCIENCE.) 12mo. 357 pages. \$1.50.

The aim of this book is to exhibit the scientific connection of the various steps by which our knowledge of the Phenomena of Heat has been extended. It treats of Thermometry, Calorimetry, Lines of Equal Temperature on the Indicator Diagram, Adiabatic Lines, Heat Engines, Latent Heat, Thermodynamics of Gases, Free Expansion, Determination of Heights by the Barometer, Radiation, Convection Currents, Diffusion of Heat by Conduction, Diffusion of Fluids, Capillarity, Elasticity and Viscosity, Molecular Theory of the Constitution of Bodies, etc., etc.

* * For other books on the subjects of Sound, Light, and Heat, see Longmans, Green, & Co.'s Educational Catalogue.

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

ELEMENTARY PHYSICS.

By MARK R. WRIGHT, author of "Sound, Light, and Heat." With 238 Illustrations. 12mo. 256 pages. 80 cents.

This work will serve as a suitable text-book for any class beginning the study of physics. The leading facts are brought under the notice of the student by easy experiments that do not demand expensive apparatus. Full instructions are given for the construction of the apparatus, in the text, or in the appendix. The author believes that in early lessons it is inadvisable to trouble the student either with theories or with the generalizations that prove such a valuable aid to the advanced student.

BOWDOIN COLLEGE.

"I consider it very well adapted to beginners in the science. The long list of experiments affords ample material from which a course of any length may be adapted. The whole trend of the book is in the right direction—the teaching of physics by experiment."—C. C. HUTCHINS, Brunswick, Me.

"It should take high rank, and come into wide use among our schools."—*Education*, Boston.

"This book possesses considerable merit. The matter contained in it is just about as much as would cover the course usually taken in a year's school work; the explanatory text is couched in the clearest language, and the experiments described are capable of being easily brought to a successful termination. . . . The book compares most favorably with any written for the purpose of imparting a rudimentary knowledge of magnetic and electrical phenomena."—*Nature*.

"The treatment is simple and clear, and the experiments given are admirably chosen; by their aid the subject is logically developed, and they are such as can be performed with very simple apparatus. . . . Altogether, this is one of the best primary books on physics that we have seen."—*Critic*, New York.

PRACTICAL PHYSICS.

By R. T. GLAZEBROOK, M.A., F.R.S., and W. N. SHAW, M.A., Demonstrators at the Cavendish Laboratory, Cambridge. With Woodcuts. (TEXT-BOOKS OF SCIENCE.) Fourth Edition. Revised and Enlarged. Crown 8vo. 260 pages. \$2.50.

This book is intended for the Assistance of Teachers and Students in Physical Laboratories. It contains chapters on Physical Measurements, Units of Measurements, Physical Arithmetic, Measurement of the more Simple Quantities, Measurement of Mass and Determination of Specific Gravities, Mechanics of Solids, Liquids, and Gases, Acoustics, Thermometry, and Expansion. Calorimetry, Tension of Vapor and Hygrometry, Photometry, Mirrors and Lenses, Spectra, Refractive Indices and Wave-Lengths, Polarized Light, Color Vision, Magnetism, Electricity, Experiments in the Fundamental Properties of Electric Currents, Ohm's Law, Galvanometric Measurement of a Quantity of Electricity, etc., etc.

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

SOUND, LIGHT, AND HEAT.

By MARK R. WRIGHT, author of "Elementary Physics." With 162 Illustrations and Diagrams. 12mo. 272 pages. 80 cents.

This volume is an elementary text-book on Sound, Light, and Heat, treated experimentally. It is essential that the experiments should be performed. The numerical results which illustrate the text should not take the place of measurements made by the student. The experiments demand no expensive apparatus; the aim has been to avoid elaborate instruments; descriptions of the apparatus used appear in the book or in the appendix. Examples are given frequently throughout the work.

HEAT.

A Manual for Students in Advanced Classes.

By MARK R. WRIGHT. With numerous Illustrations and Diagrams. Crown 8vo. \$1.50.

"A well-planned and well-executed work. . . . The book is in physics what Remsen's text-book is in chemistry, a well-prepared outline of the theory and experimental method of exposition of the science."—*Science*, N. Y.

PHYSICAL OPTICS.

By R. T. GLAZEBROOK, M.A., F.R.S., Fellow and Lecturer of Trinity College; Demonstrator of Physics at the Cavendish Laboratory, Cambridge. With 183 Woodcuts of Apparatus, etc. (TEXT-BOOKS OF SCIENCE.) 12mo. 448 pages. \$2.00.

Contents.—Wave Motion, The Rectilinear Propagation of Waves, Reflection and Refraction, Prisms and Lenses, Interference, Colors of Thin Plates, Diffraction, Dispersion and Achromatism, Spectrum Analysis, Absorption and Anomalous Dispersion, Double Refraction, Refraction and Reflection of Polarized Light, Interference of Polarized Light, Circular Polarization, Electro-Optics, The Velocity of Light, etc., etc.

THEORY OF HEAT.

By J. CLERK MAXWELL, M.A., etc., etc. Tenth Edition, with Corrections and Additions by LORD RAYLEIGH, Sec. R. S. (TEXT-BOOKS OF SCIENCE.) 12mo. 357 pages. \$1.50.

The aim of this book is to exhibit the scientific connection of the various steps by which our knowledge of the Phenomena of Heat has been extended. It treats of Thermometry, Calorimetry, Lines of Equal Temperature on the Indicator Diagram, Adiabatic Lines, Heat Engines, Latent Heat, Thermodynamics of Gases, Free Expansion, Determination of Heights by the Barometer, Radiation, Convection Currents, Diffusion of Heat by Conduction, Diffusion of Fluids, Capillarity, Elasticity and Viscosity, Molecular Theory of the Constitution of Bodies, etc., etc.

*** For other books on the subjects of Sound, Light, and Heat, see Longmans, Green, & Co.'s Educational Catalogue.*

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

ELEMENTARY PHYSICS.

By MARK R. WRIGHT, author of "Sound, Light, and Heat." With 238 Illustrations. 12mo. 256 pages. 80 cents.

This work will serve as a suitable text-book for any class beginning the study of physics. The leading facts are brought under the notice of the student by easy experiments that do not demand expensive apparatus. Full instructions are given for the construction of the apparatus, in the text, or in the appendix. The author believes that in early lessons it is inadvisable to trouble the student either with theories or with the generalizations that prove such a valuable aid to the advanced student.

BOWDOIN COLLEGE.

"I consider it very well adapted to beginners in the science. The long list of experiments affords ample material from which a course of any length may be adapted. The whole trend of the book is in the right direction—the teaching of physics by experiment."—C. C. HUTCHINS, Brunswick, Me.

"It should take high rank, and come into wide use among our schools."—*Education*, Boston.

"This book possesses considerable merit. The matter contained in it is just about as much as would cover the course usually taken in a year's school work; the explanatory text is couched in the clearest language, and the experiments described are capable of being easily brought to a successful termination. . . . The book compares most favorably with any written for the purpose of imparting a rudimentary knowledge of magnetic and electrical phenomena."—*Nature*.

"The treatment is simple and clear, and the experiments given are admirably chosen; by their aid the subject is logically developed, and they are such as can be performed with very simple apparatus. . . . Altogether, this is one of the best primary books on physics that we have seen."—*Critic*, New York.

PRACTICAL PHYSICS.

By R. T. GLAZEBROOK, M.A., F.R.S., and W. N. SHAW, M.A., Demonstrators at the Cavendish Laboratory, Cambridge. With Woodcuts. (TEXT-BOOKS OF SCIENCE.) Fourth Edition. Revised and Enlarged. Crown 8vo. 260 pages. \$2.50.

This book is intended for the Assistance of Teachers and Students in Physical Laboratories. It contains chapters on Physical Measurements, Units of Measurements, Physical Arithmetic, Measurement of the more Simple Quantities, Measurement of Mass and Determination of Specific Gravities, Mechanics of Solids, Liquids, and Gases, Acoustics, Thermometry, and Expansion. Calorimetry, Tension of Vapor and Hygrometry, Photometry, Mirrors and Lenses, Spectra, Refractive Indices and Wave-Lengths, Polarized Light, Color Vision, Magnetism, Electricity, Experiments in the Fundamental Properties of Electric Currents, Ohm's Law, Galvanometric Measurement of a Quantity of Electricity, etc., etc.

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.

TELEPHONE LINES AND THEIR PROPERTIES.

By Prof. W. J. HOPKINS, of the Drexel Institute, Philadelphia. With numerous Illustrations. New Edition, Revised and Enlarged. 12mo, \$1.50.

The intention of the author has been to provide a book which should prove useful to the practical man, as well as one which would serve as a basis for a lecture course to students. He has therefore thought it desirable to devote some space to the development of correct elementary ideas of matter and energy so as to lead up to the most modern conception of the method of propagation of electro-magnetic disturbances.

From the *Electrical World*, N. Y.

"This useful work . . . deals with the design, construction, and material of telephone lines, aerial and underground, and with their electrical properties. . . . The subjects are treated in such a way as to prove interesting and instructive to the general reader as well as to the technical student, and the few mathematical demonstrations are put in foot-notes. While the theoretical principles governing the various matters treated are explained, particular attention is paid to their practical applications, the book combining in a happy manner correct theory with correct practice. . . . A useful addition to the literature upon the subject, and can safely be recommended."

From the *Commercial Advertiser*, N. Y.

"A thoroughly systematized and lucidly written little work, which is almost the first complete exposition of the progress of electrical science as applied to the construction and operation of the telephone."

From the *Transcript*, Boston.

"Though primarily intended for the student, was nevertheless written with an eye to making it easy of comprehension to the general reader. It covers everything relating to telephone. The volume will be worth its weight in gold to the student, as it covers the ground more completely than any other existing work."

From the *Nation*, N. Y.

"The practical part of the book is the result to a large degree, we infer, of personal experience, and is therefore good."

From the *Scientific American*, N. Y.

"Seems really to have filled a want existing in technical literature. We are convinced that in its practical details, as well as its examination of induction and the properties of telephone lines, it will be of great use to the practical man, as well as of interest to the student. It is very fully illustrated and can be confidently recommended to electricians."

LONGMANS, GREEN, & CO., 15 East Sixteenth Street, New York.





This book should be returned to
the Library on or before the last date
stamped below. *

A fine of five cents a day is incurred
by retaining it beyond the specified
time.

Please return promptly.

